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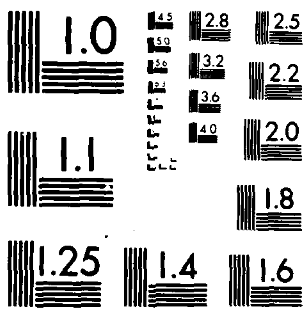

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ST. LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

GEOTECHNICAL REPORT

DEPARTMENT OF THE ARMY
BUFFALO DISTRICT, CORPS OF ENGINEERS
BUFFALO, NEW YORK

MARCH 1981

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This report presents geotechnical data used to assist in the selection of future additional lock and channel locations at four proposed alternative sites along a section of the St. Lawrence Seaway. The proposed alternatives include: "Twin" locks at the existing Eisenhower and Snell locks, a single high-lift lock with the construction of a new channel, and an additional lock near Iroquois Dam at Point Rockway with construction of a new channel. All the proposed alternative sites are located within the territory of the United States along the St. Lawrence Seaway stretching from near Iroquois Dam

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downstream to the eastern tip of Cornwall Island near Cornwall, Ontario. Three of the sites, Eisenhower and Snell "Twins" and the high-lift are located at the eastern end of the area, northeast of Massena, New York; and the fourth site, Iroquois-Point Rockway, at the western end near Waddington, New York.

The report presents data from a review of literature and includes subsurface and geophysical exploration data, observations arrived at from on-site reconnaissance and discussions with individuals familiar with the areas in question, examination of existing rock core samples previously taken at some of the proposed sites, summaries of field and laboratory testing and geologic profiles and sections based on data from previous subsurface exploration programs.

Substantial geotechnical data was obtained from investigations conducted for the existing Eisenhower and Snell Locks. A large portion of this data was obtained at locations which are in the areas of the proposed Eisenhower and Snell "Twin" Locks. Data regarding subsurface conditions for the Iroquois-Point Rockway and high-lift sites are very limited and sketchy.

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ADDITIONAL LOCKS STUDY

GEOTECHNICAL REPORT

DEPARTMENT OF THE ARMY
BUFFALO DISTRICT, CORPS OF ENGINEERS
BUFFALO, NEW YORK

MARCH 1981

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PREFACE

The geotechnical report was prepared by Tippetts-Abbett-McCarthy-Stratton, (TAMS) Engineers, Architects and Planners, under contract No. DACW49-80-C-0002, Work Order No. 1 for the U. S. Army Engineer District, Buffalo.

For the preparation of this report, the Buffalo District furnished in preliminary rough draft form a number of the plates and figures, the laboratory test results, geophysical surveys, drilling logs and pressure test data.

Mr. Thomas Bobal of TAMS prepared the report under the guidance of Mr. Harvey Feldman, Project Study Manager. Mr. Mel Hill, Project Manager for the Corps, reviewed the work by TAMS under the supervision of Mr. T. A. Wilkinson, Chief, Geotechnical Section. All Corps work was under the direction of Mr. J. A. Foley, Chief, Design Branch and Mr. Donald M. Liddell, Chief, Engineering Division. Lt Col. Thomas L. Braun, Deputy District Engineer, was the Contracting Officer.

1. INTRODUCTION

The purpose of this report is to present geotechnical data to assist in the selection of future additional lock and channel locations at four proposed alternative sites along a section of the St. Lawrence Seaway. The proposed alternatives include: "Twin" locks at the existing Eisenhower and Snell Locks, a single High-Lift lock with the construction of a new channel, and an additional lock near Iroquois Dam at Point Rockway with construction of a new channel. All the proposed alternative sites are located within the territory of the United States along the St. Lawrence Seaway stretching from near Iroquois Dam downstream to the eastern tip of Cornwall Island near Cornwall, Ontario. Three of the sites, Eisenhower and Snell "Twins" and the High-Lift are located at the eastern end of the area, northeast of Massena, New York (See Plate 1) and the fourth site, Iroquois-Point Rockway, at the western end near Waddington, New York.

The report presents data from a review of literature and previously submitted reports, includes subsurface and geophysical exploration data, observations arrived at from on-site reconnaissance and discussions with individuals familiar with the areas in question, examination of existing rock core samples previously taken at some of the proposed sites, summaries of field and laboratory testing and geologic profiles and sections based on data from previous subsurface exploration programs.

Substantial geotechnical data was obtained from investigations conducted for the existing Eisenhower and Snell Locks. A large portion of this data was obtained at locations which are in the areas of the proposed Eisenhower and Snell "Twin" Locks. Data regarding subsurface conditions for the Iroquois-Point Rockway and the High-Lift sites are very limited and sketchy.

2. REGIONAL GEOLOGY

2.1 Physiography

The project area under consideration is located in the St. Lawrence Lowland, which forms the northern section of the St. Lawrence Valley physiographic province. The lowland is a broad area, less than 1,000 feet in altitude, bordered on the north by the Laurentian plateau and on the south by the uplands of the Adirondack province, where elevations average between 1,000 and 2,000 feet.

On the basis of the varying topography found to the south of the international boundary, the St. Lawrence Lowland can be subdivided into seven fairly distinct subsections (Figure 1). Most of the southwestern half of the lowland, including the Western Tableland, Frontenac Axis, and Black Lake Tableland Subsections, is characterized by: 1) the rare occurrence and small bulk of the till deposits; 2) the large areas of exposed bedrock; 3) the close relationship of the surface topography to bedrock structure; and 4) the predominance of lacustrine sediments which lie directly on the bedrock.

By contrast, the northeastern half of the lowland - roughly that area northeast of a line connecting Ogdensburg and

Canton - has widespread deposits of till with only rare exposures of bedrock. Surface topography is controlled by the glacial deposits rather than the bedrock.

For the most part, the area is underlain by flat to gently dipping Paleozoic sediments, the erosion of which has formed the lowlands. The region underwent peneplaination during the Tertiary, followed by uplift and degradation of the softer rocks to flat-bottomed lowland. Over this late Tertiary erosion surface, the Pleistocene glaciers spread their deposits.

A gently rolling surface of low relief characterizes most of the area. Elevations range from around 150 feet in the northeast near Cornwall to more than 500 feet on some hilltops near Potsdam and Norfolk. The average relief over distances of a mile or less is about 30 feet.

Drainage of the area is controlled by the St. Lawrence River. It flows northeastward 270 miles from Lake Ontario to Quebec and another 370 miles from Quebec to Anticosti Island in the Gulf of St. Lawrence.

The St. Lawrence River has only occupied its present location since the retreat of the last Wisconsin glacier and the recession of the Champlain Sea, some 5,000-6,000 years ago. It has, therefore, not had enough time to cut a valley for itself, but simply follows a connecting chain of glacially-formed depressions, flowing around and among the small bedrock hills at its western end and the hills of glacial till farther east. Consequently, it is ungraded and, prior to construction

of the St. Lawrence Seaway, was studded with the now-submerged Galop and Long Sault Rapids.

Due to the regulating effect of Lake Ontario on the surface water discharge, the river is not subject to extreme floods and low water as are normal rivers. By eroding fine material which its normal flow can handle, it has left behind coarser material which acts as an armor protecting the banks from further erosion. Because of this, the St. Lawrence has accomplished relatively little erosion for so large a river.

The three major tributaries to the St. Lawrence from the south - the Grass, Raquette and St. Regis Rivers - also follow valleys made for them by the pattern of glacial deposits. All flow northward off of the Adirondack highlands and then turn eastward upon approaching the St. Lawrence trough to follow the elongate depressions between morainal ridges for several miles before joining the main stream. Many smaller streams flow into these rivers or directly into the St. Lawrence and show a great deal of seasonal fluctuation in discharge. Extensive marshlands are found throughout the area but there are few natural lakes.

2.2 Surficial Geology

The bedrock in the northeastern half of the St. Lawrence Lowland is overlain by a blanket of glacial drift which varies in thickness up to more than 200 feet in places. These unconsolidated deposits were laid down in late Pleistocene time during and after the Wisconsin glaciation. The deposits

comprise: (1) till laid down by the glacial ice; (2) clay and other materials deposited in standing bodies of water during and after melting back of the ice; (3) deposits formed by the modification of the till and other sediments; and (4) materials laid down after the large bodies of standing water had been drained. The most complete sequence of these deposits can be seen near Lake St. Lawrence.

On the basis of till fabric and the striations found on underlying rock surfaces, two separate glacial episodes can be identified. The earlier one, the Malone glaciation, moved southwest up the St. Lawrence valley and then spread over the Adirondacks. The Malone has been correlated with the Cary sub-stage of the Wisconsin standard section in the midwestern United States. The later Fort Covington invasion crossed the valley from northwest to southeast and extended only as far as the northern flank of the Adirondack upland. It has been correlated with the Valders substage, the final Wisconsin advance.

With the retreat of the Fort Covington glacier and the formation of an ice barrier in the lower St. Lawrence valley, a fresh-water proglacial lake (Lake Fort Ann) was created covering most of the area. A break in the ice barrier drained the lake, and the subsequent eustatic rise of sea level (due to the inflow of meltwaters from the retreating glaciers) permitted flooding of the lowland by marine waters of the Champlain Sea. The earth's crust, which had been deformed under the enormous

weight of the glaciers, gradually began to rebound. The isostatic rise of the land was more rapid than the eustatic rise in sea level, causing the Champlain Sea to recede. This uplift of the land is still occurring to this day.

Three layers of till can be distinguished in the area: the Lower and Middle tills of the Malone episode, and the Upper till of the Fort Covington. The Lower till was deposited over the dolomitic bedrock during the first advance of the Malone glacier from the northeast. It consists of blue-gray, unstratified, mixed deposits of clay, silt, sand and stones. This till, especially that portion immediately overlying bedrock, contains most of the dense, tough basal (lodgement) till that caused difficulties in excavations for the St. Lawrence Seaway. The Lower till is commonly 10-40 feet thick and is widely found in the subsurface in the vicinity of Lake St. Lawrence and probably present throughout the area.

With the recession of the ice front and the formation of a proglacial lake, varved clays and interbedded silt, sand and gravel were deposited on top of the Lower till.

Another glacial advance from the northeast led to the deposition of the Middle till. This till does not differ markedly from the Lower till except in being weathered in some places. It is brown to blue-gray in color and moderately to very dense. It consists of mixed deposits of clay, silt, sand and stones, and although unstratified, it is interbedded in part with the underlying lake deposits. The relationship

between the Middle till and zones of stratified drift and sediments is very complex and varies throughout the area. Water-bearing sandy and silty deposits in the till have been found in many hills.

The Lower and Upper tills have been readily distinguished in the walls of several open excavations because of the presence of permeable materials, from which ground water seeped, at the top and bottom of the Middle till.

The recession of the Malone glacier and formation of a proglacial lake again allowed the deposition of varved clays and interbedded silt, sand and gravel.

The Fort Covington glacier, advancing now from the northwest, deposited the Upper till. It is similarly an unstratified, mixed deposit of clay, silt, sand and stones; brown to blue-gray in color; and moderately dense and compact. Commonly 20-60 feet thick, it underlies most of the area and is locally mantled by outwash gravel and sand.

With the recession of the Fort Covington ice and the formation of Lake Fort Ann, varved clays were again laid down along with mixed (slumped) deposits of silt, sand, and gravel containing enclosed masses of till.

Continued recession of the ice front and the subsequent invasion of salt-water brought about formation of the Champlain Sea. In this marine environment were deposited post-glacial marine clays in the lowland areas carved out by the previous glaciation. The clay is blue-gray, extremely sensitive, soft

and sticky and contains marine shells and inclusions of plant material. It is commonly 30-60 feet thick. Some thin nearly horizontal lenses of stratified sands and silts are found locally, particularly in areas adjacent to till deposits.

As the Champlain Sea receded, a blanket of marine sand, some 1-10 feet thick, was laid down on the underlying marine clay in the lowlands. Sand and gravel, in the form of beach deposits and deposits of reworked, or winnowed, till, were formed on the tops and sides of many till ridges.

The continued uplift of the land brought about the development of the channels of the St. Lawrence River and its tributaries by the erosion of the glacial and post-glacial deposits. This process is still occurring and deposits of gravel, sand, silt and clay are being formed in and beside stream channels throughout the area. Locally, in poorly drained areas, peat is being formed.

2.3 Bedrock Geology

The only large expanses of exposed bedrock in the St. Lawrence Lowland occur in the southwestern half of the area. Northeast of the Ogdensburg-Canton line the bedrock is covered nearly everywhere by glacial drift and outcrops appear only locally in stream beds and at a few other places. Much valuable information on the bedrock stratigraphy was obtained during exploratory work and excavations made for the St. Lawrence Seaway project.

The lowland is underlain predominantly by flat-lying or gently dipping lower Paleozoic sedimentary rocks (see Plate 2).

These rocks of chiefly Cambrian and Ordovician age overlie a basement complex of Precambrian crystalline rocks. Major unconformities separate the Precambrian from the Paleozoic rocks and the Paleozoic rocks from the Pleistocene glacial drift.

2.3.1 Precambrian Rocks

The basement consists of a complex series of intensely folded, highly metamorphosed sedimentary rocks (limestones, quartzites, schists and gneisses) into which were intruded various types of igneous rocks. This late Precambrian formation is referred to as the Grenville Series. The nearest exposure of the basement rocks in the Lake St. Lawrence area is a reddish granite gneiss which outcrops some 5 miles west of Potsdam. Several deep water wells in the southern part of the area are reported to have penetrated crystalline rock but no details are given in the well records as to the rock structure. A deep test hole drilled in 1900 at Massena reportedly penetrated granite after passing through 500 feet of limestone and several hundred feet of yellow, red and white sandstone.

2.3.2 Paleozoic Rocks

Nearly the entire lowland is underlain by lower Paleozoic sedimentary rocks, chiefly dolomite with subordinate limestone and sandstone. Ordovician dolomite and limestone underlie most of the area in the north and northwest. A broad band of Cambrian or Ordovician sandstone, with some interbedded dolomite, borders the dolomite on the southeast and south. Although

outcrops are rare, the gross lithologic character of the rocks is fairly well known from the hundreds of wells which penetrate them, but few detailed well records have been preserved. The thickest section known at a single place is at Massena where the previously mentioned deep test hole went through hundreds of feet of limestone and sandstone. An estimated thickness of 500-600 feet of Paleozoic rocks has been reported at Cornwall. All the Paleozoic strata were slightly deformed after early Ordovician time.

2.3.2.1 Potsdam Sandstone

The lowermost Paleozoic formation around the base of the Adirondacks is the Potsdam Sandstone, which is separated from the Precambrian basement by a major unconformity. Due to the very slow northward transgression of the shallow Cambrian Sea, the Potsdam ranges in age from Late Cambrian in central New York to Early Ordovician along the border of the Canadian Shield. It is named for outcrops around Potsdam, New York, but is not well exposed there. One of the best exposures in the near vicinity is along the St. Regis River at Brasher Falls. In some areas, the Potsdam is locally strongly folded, and is characterized by patchy distribution which suggests deposition on an irregular surface, later erosion, or both.

In its type locality, the Potsdam is a fine- to medium-grained quartz sandstone (essentially a quartzite) which is commonly pebbly at its base. Due to the presence of hematite as a cementing agent, the rock is typically reddish-brown in color, but beds of white sandstone and gray sandstone are also

present. It is the hardest and most substantial and resistant of the sedimentary formations. The red sandstone was once used extensively in buildings and pavements in the village of Potsdam. The formation is about 200 feet thick in St. Lawrence County.

2.3.2.2 <u>Theresa Formation</u>

The Theresa Dolomite represents a series of transitional beds between the Potsdam Sandstone and the dolomitic rocks of the Beekmantown Group. It ranges from Late Cambrian to Early Ordovician in age. It has been arbitrarily separated from the Potsdam, where both formations are present, at the lowermost dolomite layer in the sequence. At its type locality north of Watertown in Jefferson County, the Theresa is about 300 feet thick. To the northeast, it is probably somewhat thinner and consists primarily of white, gray or brown sandstone, in part calcareous, with subordinate dolomite and shale. Included in the Theresa are the Heuvelton Sandstone (a bed of white sandstone some 20 feet thick) and the lower part of the Bucks Bridge mixed beds. The Bucks Bridge is sandy in the lower part and dolomitic in the upper part, and lies between the Heuvelton Sandstone and the Ogdensburg Dolomite. In many places the contact between the Theresa and rocks of Beekmantown Age is difficult to recognize and the relation between the rocks may be a gradational one.

2.3.2.3 <u>Beekmantown Group</u>

The Ordovician Beekmantown Group in this area consists of

the upper part of the Bucks Bridge mixed beds and the Ogdensburg Dolomite, which is essentially equivalent to Division D of the classic Beekmantown section in the Champlain Valley. The rocks are largely black dolomite and gray dolomite containing subordinate limestone, sandstone and shale. Pyrite is widely distributed through the rock as disseminated crystals. Gypsum is common, mostly in small veins and thin layers, but locally it has been found in beds 3 to 5 feet thick.

The Beekmantown represents the uppermost bedrock for a wide expanse from Massena to Ogdensburg and beyond in both directions. At Massena, the dolomite is 500 feet thick and may be even thicker near its contact with the rocks of the Chazy Group along the St. Lawrence River.

2.3.2.4 Chazy Group

A disconformity separates the Beekmantown from the overlying Chazy Group, which is also Ordovician in age. The contact between the two lies along the St. Lawrence River from north of Iroquois Lock to near Cornwall, Ontario. The two groups are quite similar in many respects, but the Chazy consists chiefly of limestone and sandstone with some dolomite and shale. The rock is light gray to almost black in color and approximately 80 feet thick near Long Sault Dam. The formation thickens northward into Canada.

2.3.2.5 Trenton and Black River Groups

The Chazy and the overlying undifferentiated Trenton and Black River Groups are separated by a minor disconformity. The

Trenton-Black River are of Ordovician age and are referred to in Canada as the Ottawa Formation. The rocks outcrop along the Canadian side of the St. Lawrence River west of Cornwall, and consist of gray limestones with some interbedded shale, sandstone and dolomite.

2.4 Structural Geology

The bedrock underlying this section of the St. Lawrence Lowland forms part of the southeast limb of a northeast trending basin, the greater part of which lies on the Canadian side of the river in Ontario and Quebec. The basin is about 100 miles long and some 70 miles wide, extending northwestward from the foothills of the Adirondacks to the Canadian Shield.

2.4.1 Folding

Where exposed, the Paleozoic rocks are found to be either flat-lying or else dipping at 5 degrees or less. In most exposures where the beds are not flat-lying, the strike of the bedding is northeast and the dip northwest; in a few places the beds strike northwest and dip northeast or southwest. In the Canton quadrangle, it has been found that the structure is characterized by folds which strike northeast and by irregular folds, including small domes, which trend in other directions. All indications suggest that in general the strata in this area dip gently northwestward in a homoclinal structure interrupted by tracts of flat-lying or gently folded rocks.

2.4.2 Faulting

Numerous faults have been mapped north of the St. Lawrence River, most of them in the northern part of the lowland near the

edge of the Canadian Shield. The faults are of the tensional type and strike along two dominant trends, northeast or east and northwest. Near Ottawa the faults are known to have steep dips.

A major fault striking NW-SE is located on the Canadian side of the St. Lawrence River, northwest of Massena. If extended southeast, it would enter New York about 3 miles southwest of the Massena Power Canal. A well in this area contains highly mineralized water and natural gas, suggesting the presence of a fault trap.

Another fault zone some 200 feet wide was uncovered during excavation for Snell Lock (see Section 3.4.1).

2.4.3 Joints and Fractures

Inclined to near vertical jointing is common in all of the consolidated rocks in this area. Isostatic rebound after the retreat of the Pleistocene glaciers was a major factor in producing the jointing. Because of enlargement by solution, joints in the dolomite bedrock are the most conspicuous. From the examination of outcrops, however, it appears that the joints have not been widened appreciably below the uppermost foot of rock. Moreover, driller's reports indicate that at depth wide openings in the rock are relatively uncommon in most of the area. However, several borings, especially at Snell and Eisenhower Locks, have encountered openings at depths as great as 50 feet into bedrock. In these places the openings were probably formed by the solution of gypsum.

In a few places joints in exposed dolomite have been widened to form small sinkholes at the land surface. Extensive solution openings were probably developed in the dolomite throughout the area in the past, but the upper part of the rock, containing most of these openings, was then removed by glacial erosion.

Horizontal or gently dipping fractures, more or less parallel to the bedding of the dolomite, have been observed in quarry walls. They are wider and more numerous than steeply-dipping fractures. This is confirmed by well data which indicate that the horizontal permeability of the dolomite is commonly much greater than the vertical permeability.

Other types of openings of minor importance have been observed in the dolomite. These include cavities, up to an inch or more in diameter, which are either open or filled with calcite. However, no extensive inter-connections have been found.

2.4.4 Bedrock Surface

In general, the surface of the bedrock slopes northward. Its most prominent feature is a broad valley which trends northeast, passing beneath Madrid and Raymondville. A smaller valley underlies the peninsula separating the St. Lawrence and Grass Rivers near Snell and Eisenhower Locks. Land-surface topography in this area is controlled predominantly by glacial deposits and no consistent relationship exists between the configuration of the bedrock surface and that of the present

land surface. Therefore, reliable estimates of the depth to bedrock cannot be made on the basis of land-surface topography alone.

2.5 Seismicity

The St. Lawrence Lowland is a region of relatively high seismic activity. On the Seismic Risk Map of the United States (Figure 2), the area has been given a Zone 3 classification. This means that major damage could occur due to seismic activity.

The historical record of earthquake occurrences has been traced back to 1534. Several shocks with intensities as high as IX and X (on the Modified Mercalli Scale of 1931) have been recorded on the Canadian side of the lowland. In New York, intensities in the range of IV-V are more common, and shocks greater than VIII have not been observed (Coffman and Von Hake, Ref. 5).

2.5.1 Massena-Cornwall Earthquake

The Massena-Cornwall earthquake of September 4, 1944 reached an intensity of VIII. It was estimated to have affected an area of some 175,000 square miles, from Maine to Michigan and as far south as Pennsylvania and Maryland. The epicenter was located near the small community of Massena Center, partway between the larger towns of Massena and Cornwall. Damage in the central area was about $2 million for the two towns. About 90 percent of the chimneys in Massena were destroyed or damaged, with similar damage at Cornwall. The effects of the shock were not distributed in a regular fashion throughout the general

area. The greatest disturbance occurred where the surface was underlain by clay and silt; structures founded on rock or on till were not damaged appreciably. A report by Charles P. Berkey (Ref.2) presents a detailed account of the destructive effects of the earthquake. More recently, two earthquakes of intensity V struck Massena in 1961 and 1964.

2.5.2 Seismogenic Provinces

For a long time earthquakes in this region have been explained by the readjustment of the earth's crust, subsequent to the final retreat of the Pleistocene glaciers. It has been suggested that the ice load deformed the crust during the glacial periods, and now it is gradually coming back to its normal position. As the adjustments may occur deep within the earth, major surface faulting, which is rare in this region, need not be present.

Numerous attempts have been made to recognize trends in seismicity and relate them to regional geology or tectonics. One proposal defined a continuous seismic zone along the St. Lawrence River, possibly extending as far south as Arkansas. Another zone of seismicity transverse to the Appalachian trend extending from Boston to Ottawa has been suggested. An attempt to correlate earthquakes with mafic intrusives has also been put forward.

But recent work by Yang and Aggarawal (Ref. 18) on the seismicity of the northeastern U.S. finds no convincing evidence for these theories. Their study leads them to distinguish two distinct seismogenic provinces: (1) the Appalachian Province, a

northeasterly trending zone of seismic activity extending from northern Virginia to New Brunswick, Canada; and (2) the Adirondack - Western Quebec Province.

The Adirondack - Western Quebec Province is a northwesterly trending zone, about 200 kilometers wide and at least 500 kilometers long, extending from the Southeast Adirondacks into Western Quebec, Canada. Thrust faulting on planes striking NNW to NW appears to predominate and the inferred axis of maximum horizontal compression is largely uniform and trends WSW, nearly parallel to the calculated absolute plate motion of North America. Little or no seismicity is found where anorthosite outcrops at the surface. The zone does not extend southeastwards to Boston as some have proposed.

Northeast of this province and separated from it by a relatively aseismic area, there is a distinct concentration of earthquake epicenters around La Malbaie, Quebec. The epicenters apparently trend parallel to the St. Lawrence River valley but most of the activity is concentrated in the so-called "Charlevoix zone". Similarly, to the southwest of the province, and not connected to it, there is a pattern of earthquake activity in western New York and western Lake Ontario which is suggestive of a WNW trend transverse to the Central Appalachian fold belt.

Some important conclusions from the Yang-Aggarwal study are:

(1) Seismic activity in the northeast is relatively stationary in space: those areas that have had little or no

seismicity historically are relatively aseismic today, whereas the historically active areas are also active today.

(2) No convincing evidence was found for a continuous zone of seismic activity parallel to the St. Lawrence River, nor for the existence of a Boston-Ottawa seismic zone transverse to the Appalachian trend.

(3) Earthquakes in the Adirondack - Western Quebec area apparently respond to a WSW directed maximum compressive stress related to the plate motion of North America.

(4) The presence of unfaulted igneous intrusives (plutons, batholiths, sills, etc.) apparently inhibits rather than facilitates the occurrence of earthquakes.

2.6 Ground Water

Trainer and Salvas (Ref. 9) carried out a detailed investigation of the ground-water conditions in the Massena-Waddington area of the St. Lawrence Lowland. Their findings hold true for most of the Oriented Till Ridges Subsection where the additional locks project is under study. The following is abstracted from their report.

2.6.1 Aquifers

The unconsolidated deposits lying between the major streams of the area form an unconfined aquifer in which till and sand are the chief water-bearing materials. Confined aquifers are also present but are apparently of small lateral extent; they include the washed drift interbedded with the till sheets and layers of sandy material in the till. All of these

unconsolidated aquifers are of low to moderate permeability. Recharge is accomplished by water percolating from the land surface, and locally (immediately along the dikes), from Lake St. Lawrence. The aquifers discharge into the underlying bedrock and into marshes and streams.

The most dependable water supplies in the area, including all the large sources, are obtained from aquifers in the bedrock. The upper part of the bedrock forms a single, more or less continuous aquifer which is confined (artesian) in most places. One or more aquifers also occur at deeper levels in the rock. The bedrock aquifers are recharged by percolation from the overlying deposits in interstream areas and discharge into the major surface streams. Fractures (which appear to be primarily parallel to the bedding but which also include cross joints) are the most important openings and waterways in the bedrock. Intergrain porosity is of little or no consequence. Areal and vertical variations in the size and spacing of the rock openings, and the better development of horizontal openings than those which dip steeply, prevent the accurate prediction of well depths and yields. In general, transmissivity values of the dolomite range from 1,000 to 10,000 gallons per day per foot, but some values as high as 20,000 to 68,000 gpd per foot were determined for several wells.

2.6.2 Water Chemistry

"The ground water is of the calcium magnesium bicarbonate type. In the unconsolidated deposits, and in the upper part of the bedrock in recharge areas, the water is

generally of good quality except for high hardness and ojectionable iron in some places. Water from deeper parts of the bedrock contains higher concentrations of dissolved solids and of chloride; in some places these concentrations exceed the maximum limits recommended by the U.S. Public Health Service. In many places this deeper water also contains hydrogen sulfide. Many water supplies from the deep bedrock aquifers are artificially softened, or have the hydrogen sulfide removed by aeration or by chlorination. This deeper, more mineralized water may be Champlain Sea water, older sea water (connate water) long trapped in the rocks, water which has been in contact with buried evaporite deposits, or a combination of such waters. The deeper water has been diluted and partly flushed from the rock by fresh water percolating from above, and at the depths commonly reached by wells in this area it is found most commonly along the rivers where the bedrock aquifers discharge. Two wells which tapped bedrock reservoirs that had previously been tightly sealed yielded highly mineralized water and natural gas. Fault traps are thought the most probable explanation of these reservoirs. The gas was in noncommercial quantities".

2.6.3 Ground Water Use

At present, ground water is being used "chiefly for domestic and farm supplies. Most of the older wells were dug wells drawing from the unconsolidated deposits; most of the newer ones are drilled wells which tap the bedrock. The wells

are relatively widely spaced, and the use of water, even for village supplies, seems to have had little effect on the quantity of water available. None of the village supplies is treated except for the aeration of one to remove hydrogen sulfide".

2.6.4 Effect of Lake St. Lawrence

With the flooding of Lake St. Lawrence in 1958, water levels rose in those bedrock wells located between the lake and the Grass River. The areas most affected lay west of Eisenhower Lock, upstream to near Waddington. In some low areas artesian flow was produced where none had previously occurred. And in another area the direction of ground water flow was reversed. A more detailed discussion of the lake effects can be found in Trainer and Salvac (Ref. 9).

3. LOCAL GEOLOGY

3.1 Physiography

The proposed alternative lock sites at Iroquois, Eisenhower, Snell and High-Lift are located in the northeastern half of the St. Lawrence Lowland in the Oriented Till Ridges Subsection. The land is covered by a belt, about 18 miles wide, of low, elongate ridges of till rising from clay and sand-filled intervening lowlands. The mounds of till trend in a northeast-southwest direction and are elongated parallel to the St. Lawrence River. These ridges have been worn down by waves and currents of the post-glacial Champlain Sea. The fine-grained constituents of the till were winnowed out by wave action and washed into the lowlands. This left a coarse stony debris

containing marine shells capping the crest of many of the hills. It has been estimated that the morainal topography has been lowered 20 feet or more by this wave-wash and the intervening lowland raised a commensurate amount.

3.1.1 Vicinity, Snell "Twin" Alternative

The Snell alternative site is located in a flat area underlain by marine clay along the left bank of the Grass River near where that stream empties into the St. Lawrence River. It lies a short distance beyond the northeast end of a gently sloping, NE-SW trending till ridge which rises to El 250 some 3,000 feet to the southwest. Before the construction of Snell Lock, a small tributary of the Grass River flowed along the south side of the lock excavation area between the lock site and the edge of the ridge. The topography in the general area prior to construction was nearly flat, with a relief of 25 to 30 feet. The Grass River varies at about El 157 and the small tributary was about El 160. The top of the bank above the Grass River was El 175, and the land surface in the lock area was mostly between Els 180 and 185. The topography north and south of the present lock has been somewhat altered by the construction of dikes; the placement of backfill behind the lock walls; and the construction of spoil piles. The roadway on top of the dikes is about El 207; backfill behind the lock walls was placed to El 205; and spoil was placed in the spoil areas to about El 205.

3.1.2 Vicinity, Eisenhower "Twin" Alternative

The site of the Eisenhower alternative is located on a

major NE-SW trending till ridge. The ridge is between 1,500 and 2,000 feet wide and is bounded on the southeast by the sand-filled valley of Robinson Creek. Present-day relief is about 60 feet, from El 250 at the top of the ridge near Eisenhower Lock down to 190 feet at the portal of the highway tunnel. Prior to excavation for the lock, the highest point was at El 263. Robinson Creek is at about El 200. From the top of the tunnel cut, the land slopes away to the east on roughly a 2 percent grade across backfilled terrain.

3.1.3 Vicinity, High-Lift Alternative

The proposed site for the High-Lift alternative lock and channel lies to the south of the Snell and Eisenhower Locks, between the Wiley-Dondero Canal and the Grass River. The Grass River flows northeastward at about El 157 across a clay and sand-filled lowland. To the north it is bordered by the long, gently sloping, NE-SW trending till ridge mentioned previously in connection with the Snell Lock alternative. The ridge reaches El 250 at both ends - southwest of Snell Lock and south of Eisenhower Lock - and in the middle slopes down to about El 210. Several till ridges also border the Grass River to the south, and two lesser ridges can be found just north and northeast of the village of Massena Center.

In addition to the Grass River valley, two smaller lowland areas are located in the vicinity - one along Robinson Creek, and the other along the small stream which enters the Grass River at Massena Center.

3.1.4 Vicinity, Iroquois-Point Rockway Alternative

The topography at the Iroquois site is typical of this subsection. Two northeast-southwest trending ridges of glacial till, each about 1,500 feet wide, cross the area with a clay-filled lowland in between them. Maximum relief is around 60 feet, ranging from an elevation of 300 feet near the northeastern tip of the peninsula to 240 feet at the head of Whitehouse Bay. Whitehouse Bay, which borders the area to the east, was formed by the embayment of Whitehouse Creek after the construction downstream of Long Sault Dam and Lake St. Lawrence.

3.2 Surficial Geology

3.2.1 Vicinity, Snell "Twin" Alternative

The area south of the present Snell Lock (Plate 4) is relatively flat and, as mentioned previously in Section 3.1.1, is located at the northeast end of a large till ridge which stretches to the southwest some four miles to a point south of Eisenhower Lock (Plate 2). A typical cross-section through the general area would show, from top to bottom: 1) backfill material, 2) marine clay, 3) glacial till, and 4) dolomite bedrock (Plate 8). The backfill consists of material excavated during the construction of the Wiley-Dondero Canal and Snell Lock and is essentially a gravelly silty sandy clay with occasional boulders. It is thickest along the south wall of Snell Lock and the western edge of the area where it was used as embankment material. Boring C-701301 shows over 70 feet of backfill. To the south and east the backfill thins out and was not encountered at all in boring C-701310.

Underlying the backfill throughout most of the areas is a very soft marine clay. The clay was deposited in a salt-water environment during the post-glacial invasion of the Champlain Sea (see Section 2.2) and filled the "valleys" in and around the underlying glacial till. Generally speaking, prior to construction the thickness of clay was least where the thickness of till was greatest and greatest where the till thickness was least. The clay is referred to in the literature as the Leda clay, Laurentian clay or Massena clay. It has a flocculent structure, is extremely sensitive, and ranges in color from brown (in the zone of oxidation) to gray or blue-gray below the zone. Boring UD-701308A shows some 18 feet of the brown oxidized clay. During the construction of Snell Lock, the marine clay was found to range in thickness from about 10 to 12 feet near the western end of the upstream approach wall to about 70 feet in the downstream approach area. The 1970 boring program showed that in some places the entire thickness of clay had been removed during construction (boring C-701301) while elsewhere some 50 feet of the material still remains (boring C-701304).

Typical characteristics of the undisturbed clay at Snell Lock (based on laboratory test data contained in Ref. 14, Plate 5) are:

Classification	Clay (CL-CH)
Unit weight in place (wet weight)	106.6 pounds/cubic foot
Density (dry weight)	69.4 pounds/cubic foot
Specific gravity, G	2.82
Liquid limit	50.3
Plastic limit	25.1
Moisture content	53.6 percent
Void ratio	1.54
Cohesion, c	0.43 tons/square foot

In some areas the marine clay overlies glacial till (borings C-701301, C-701304, C-701305, C-701306, C-701307 and C-701309), and in others rests directly upon the dolomite bedrock (borings C-701302, C-701303, C-701308 and C-701310). As shown in Figure 3, the till is confined to three general areas: 1) along the south wall of the present Snell Lock, 2) in the southwest corner of the area, and 3) southeast of the downstream guide wall of Snell Lock. The greatest thickness of till (56 feet) was found in C-701309, north of the lock. In the other borings which encountered till, the thickness averaged less than 3 feet.

During the construction of Snell Lock, an exposed section of till along the north face was mapped (MacClintock, Ref.7). It showed, from top to bottom:

1) marine sand
2) marine clay
3) varved lake clay
4) sand and gravel
5) Upper till (Fort Covington)
6) silt, sand and gravel
7) Middle (?) till (Malone)
8) dolomite bedrock

3.2.2 Area from Snell to Eisenhower Locks

The proposed channel area between Snell and Eisenhower Locks (Plates 3 to 12) is bordered on the south by the long NE-SW trending till ridge mentioned in Section 3.1.2. This ridge is capped by Fort Covington till and underlain down to bedrock by one, or in some places, both of the Malone tills (Middle and Lower tills). To the north the Wiley-Dondero Canal was excavated generally through glacial till. However, in the

vicinity of Robinson Creek, just downstream from Eisenhower Lock, the canal passed through thick deposits of marine clay nearly 80 feet deep. Farther downstream, closer to Snell Lock, two additional clay-filled valleys were encountered.

3.2.3 Vicinity, Eisenhower "Twin" Alternative

The Eisenhower alternative site (Plate 11) lies across one of the typically NE-SW aligned hills of the region. A general section through the area would show from top to bottom, a sequence of backfill, glacial till and bedrock. The marine clay, common at the Snell site, is found overlying the till only to the south (near Robinson Creek) and along the eastern slope of the hill. The backfill material is similar to that found at the Snell site and is thickest along the south wall of Eisenhower Lock where it reaches depths of over 100 feet as indicated in borings C-681210 and C-681211. It thins out to the south and east.

The soft gray marine clay is the same material encountered at Snell. Borings UDC-681202 and C-681209 indicate about 40-50 feet of the clay overlying till. Two borings farthest east (UDC-681201 and C-681208) showed about 75 feet of clay on top of dolomite bedrock.

The bulk of the hill is composed of glacial till of Malone and Fort Covington age. Geophysical studies indicated a maximum till thickness of some 110 feet near the entrance to the tunnel which runs beneath Eisenhower Lock (Figure 4). Nearby boring C-681204 showed 99 feet of till overlying bedrock (Plate 13). The till thins out to the south and east and is

only about 7 feet thick in boring UDC-681202.

During the construction of Eisenhower Lock, MacClintock was able to map a section through the east end of the excavation. From top to bottom it comprises:

1) marine beach gravels
2) Upper till (Fort Covington)
3) stratified drift, with zones of varved silts and clays 8-10 feet thick
4) Middle till (Malone)
5) stratified drift with varves
6) Lower till (Malone)
7) dolomite bedrock

The Lower till was found to be very dense and difficult to excavate.

Typical characteristics of the undisturbed glacial till at Eisenhower Lock are as follows:

Classification	Sandy silt (ML-CL) with gravel, cobbles and boulders
Mechanical analysis (not including cobbles and boulders)	
gravel	13 percent
sand	34 percent
fines	53 percent
Unit weight in place (wet weight)	149 pounds/cubic foot
Density (dry weight)	139 pounds/cubic foot
Specific gravity, G	2.74
Liquid limit	17.4
Plastic limit	10.7
Moisture content	7.5 percent
Void ratio	0.24
*Angle of internal friction, ϕ	35 degrees
*Cohesion, c	2.1 tons/square foot
*Coefficient of permeability, K	48×10^{-6} centimeters/second

*Averages from tests on only three samples

At the eastern brow of the hill, excavation revealed a mass of "crumpled till", stratified silts, gravels and sands. Since the Fort Covington till generally tends to drape over the underlying Malone tills on the slopes of hills in this region, it is thought that this mass represents a subaqueous slumping of the Fort Covington into the waters of a later proglacial lake.

3.2.4 Vicinity, High-Lift Alternative

The proposed alignment of the High-Lift alternative runs southwestward from Snell Lock parallel to the Grass River, and then near Massena Center turns to the northwest entering Lake St. Lawrence west of Eisenhower Lock (Plate 14). For most of its length, it is bordered on the north by the large till ridge referred to in Section 3.1.3. Just before reaching Robinson Creek, it cuts across the SW edge of the ridge. Two smaller hills of glacial till are traversed near Massena Center. No recent exploratory work has been done in the area, and the types of materials and the depths of surficial deposits can only be roughly approximated from available water well logs. Typically in the area, the till hills are capped with Fort Covington drift, and below one or both of the Malone tills are also likely to be present. The log of well number 457-450-7, for example, shows three distinct till layers separated from each other by water-bearing sand and gravel layers. The drift is 50 to 100 feet thick, lying on a roughly horizontal bedrock surface.

South of the till ridge, the land is flat and low-lying and is underlain by clay and silty clay with, in parts, a

coating of a few feet of sand. The present-day topography is a result of the deposition of glacial drift followed by the washing and subduing effects of waves, tides, and currents of the Champlain Sea.

West of the ridge, in the area of Robinson Creek, a sequence of soft gray marine clay overlying glacial till can be expected.

3.2.5 Vicinity, Iroquois-Point Rockway Alternative

The two NE-SW oriented till ridges at the Iroquois-Point Rockway alternative site (Plate 15) are each composed of two sheets of till separated by a layer of glaciolacustrine drift. The drift layer is stratified and contains sand, clay, silt and, in places, stony to bouldery glacial material. The upper till is the Fort Covington and the lower the Malone. The intermediate stratified drift layer represents berg-rafted lake sediment deposited when Malone ice waned by calving into a lake, prior to the advance of Fort Covington ice.

Excavation for the east abutments of Iroquois Dam was carried out through more than 100 feet of drift. This exposed a section, along the north face, which showed 10 feet of fossiliferous marine clay lying on some 10 feet of varved silt and clay, underlain by buff calcareous Fort Covington till. This sequence indicates that a lake followed the Fort Covington episode, and varves as well as till were both exposed to surface oxidation prior to the marine invasion.

In another cut south of the excavation, fossiliferous marine clay in places lies directly on buff till, which becomes

blue-gray at the base of the exposure. MacClintock reports that "not only does the clay lie directly on till, but it is seen to lie in small hollows more than 10 feet deep in the surface of the till. At several places, till from tops of the little hillocks is seen to have slumped or moved out over some of the fossiliferous clay in adjacent depressions. This has produced till on top of fossiliferous clay, which would certainly be confusing if encountered in a boring sample, as has undoubtedly been done in some of the seaway explorations" (MacClintock and Stewart, Ref. 8, p. 107-110).

The exposures indicated that "the Fort Covington till had a morainal topography which was modified first by lake waters and then by marine waves and currents". Further excavations have destroyed these exposures.

The lowland area between and to the south of the two till ridges is filled with silty clays. Exploratory work done in 1941 for a proposed Point Rockway Canal alignment indicated surficial deposits in the lowlands consisting of marine clay, glacial till and water-laid or partially water-laid sands (U.S. Army, Ref. 12).

No recent exploratory work has been done in the Point Rockway area. Geologic Profile D-D on Plate 16 is based on data from the 1941 boring program. Original ground conditions have certainly been altered to some degree since construction work was begun, and detailed information as to the present-day character of the surficial deposits is not available.

3.3 Bedrock Geology

The bedrock underlying all four of the proposed additional lock sites is composed of dolomite belonging to the Ordovician Age Beekmantown Group. In the St. Lawrence Valley the uppermost Beekmantown is represented by the Ogdensburg Dolomite. The most recent borings located in the vicinity of Snell and Eisenhower Locks (1968 and 1970) penetrated the upper units of the Ogdensburg but probably did not reach the dolomite of the underlying Bucks Bridge mixed beds.

Limestone and sandstone of the Chazy Group lie above the Beekmantown, and the contact between the two groups follows the St. Lawrence River from north of Iroquois Lock to Cornwall. Chazy rocks outcrop north of the proposed additional lock sites and were not encountered in the 1968 and 1970 boring programs. They were, however, found in previous exploratory programs at the sites of the Long Sault Dam and the powerhouse on Barnhart Island.

3.3.1 Vicinity, Snell "Twin" Alternative

The bedrock is dolomite for the most part but also contains interbedded shale and dolomitic shale layers. The uppermost rock strata is thought to be 70 to 80 feet below the top of the Beekmantown. The rock has been separated into stratigraphic units based on lithology, and brief descriptions of the units are given in Table 1.

The uppermost unit at the site, Unit 27, was encountered in only one boring (C-701303) during the 1970 exploration program. Unit 23 - a dark gray to black laminated dolomitic

shale, 1 to 1.4 feet thick - shows up as a good marker bed across much of the site. Borings made during the construction of Snell Lock showed that Units 15 and 5 are replaced or partially replaced by gypsum and/or celestite in and near the fault zone (see Section 3.4) upstream from the limits of the lock walls but are unreplaced dolomite under the lock foundation. Both units were found to be leached to badly leached under the foundation area. In three of the 1970 borings (C-701301, C-701306 and C-701307), Unit 15 was missing completely (see Plate 8). Unit 1 was the lowermost unit encountered by the 1970 borings (i.e., C-701304), but hole GR-1 drilled in the fault zone (see Section 3.4.1) in 1954 penetrated into Unit 0.

3.3.2 <u>Vicinity, Eisenhower "Twin" Alternative</u>

The uppermost rock layer is 50 to 60 feet below the top of the Beekmantown. As at Snell Lock, the bedrock is predominantly dolomite with interbedded shale and dolomitic shale layers. Two gypsum beds are also present, and gypsum is irregularly distributed through some of the dolomite layers as thin seams along partings, as small stringers or veinlets, and as small irregularly shaped replacement bodies.

The rock has been separated on a lithologic basis into stratigraphic units which correlate with the same numbered units at Snell Lock (Table 1). The uppermost unit, Unit 27, was encountered in several borings during the construction of Eisenhower Lock and in three of the 1968 borings (C-681203, C-681210 and C-681211). The dark gray shale of Unit 23 again

shows up as a good marker bed across most of the site. Both Units 15 and 5 are replaced by gypsum. In the 1968 borings located downstream of approximately canal Sta. 368+00, Units 15 and 14 are almost completely missing (Plate 13). The lowermost unit, Unit 0, was penetrated only in boring AC-681208 at the extreme downstream end of the site.

3.3.3 Vicinity, High-Lift Alternative

Since the High-Lift proposed alignment runs well south of the Snell and Eisenhower Locks and the Wiley-Dondero Canal, very little boring data from any of the subsurface exploration programs carried out for the St. Lawrence Seaway Project are available. The borings within the site were performed during the 1941 program, and all terminated in the overburden without ever reaching the bedrock (Plate 14). During the 1970 boring program at Snell Lock, two holes (C-701304 and C-701310) were drilled just north of the limits for the proposed High-Lift channel and indicated dolomite bedrock. Boring C-701304 went through Unit 19 at the top of the bedrock surface down into Unit 1 and C-701304 went from Unit 25 to Unit 13 (see Table 1). None of the 1968 borings at Eisenhower Lock are located close enough to the High-Lift alignment to be of much value. Other bedrock data come from water wells located throughout the area but the information is very limited, merely describing the rock as gray to black dolomite.

3.3.4 Vicinity, Iroquois-Point Rockway Alternative

As is the case for the High-Lift site, very little boring

data are available here. No exploratory work was carried out at Point Rockway during 1968 or 1970, and the 1941 borings all cluster in the area of the proposed upstream guide wall (Plate 16). The description of the dolomite bedrock is very sketchy. It is generally characterized as a light to dark gray dolomite with numerous stringers of shale and calcite, ranging from badly broken and slightly weathered to sound. No separation into stratigraphic units was made, as at the Snell and Eisenhower Locks.

3.4 Structural Geology

The bedrock structure in the vicinity of the Snell and Eisenhower alternative sites has been fairly well defined from the many borings and geophysical survey lines across the areas. The High-Lift site has so little information available that even the top of bedrock surface can not be established with any great accuracy. Somewhat more information is available at the Iroquois-Point Rockway site, mainly from the 1940-41 boring and seismic survey investigations made for Iroquois Dam.

3.4.1 Vicinity, Snell "Twin" Alternative

The 1970 geophysical survey provides a good picture of the bedrock surface (Figure 3). It showed that "the general configuration of the surface of bedrock at the Snell Lock site starts as a high at approximate elevation 150 feet near the southwest corner of the area investigated. This high slopes to the west at a fairly uniform gradient. To the north and east of this subsurface high the bedrock surface is incised by two stream channels. The northernmost more pronounced buried stream channel cuts through the area in a northeast direction.

A small channel follows a subparallel trend just south of the larger channel. Drill holes C-701308 and C-701310 were both drilled in the vicinity of the buried channels. The seismic depths have generally been confirmed by drill holes, and the change from marine clay to bedrock is sharp with little or no rubble or debris at the contact. The absence of any gravel or debris suggests that if any detritus was present it was washed out of the channels before deposition of the marine clays" (U.S. Army, Ref. 15).

During construction in the 1950's, it was found that "the rock strata in the upstream one-fourth of the foundation area for Snell Lock are folded in a small plunging anticline, the crest of which crosses the foundation diagonally" near canal Sta. 546+50 and plunges to the northeast. "Downstream from the anticline, the rock strata are only very slightly undulated and have a slight dip northward. The dip at most places, except on the flanks of the small anticline, is less than 2 feet per 100 feet" (U.S. Army, Ref. 14).

It was also found that the movement of glacial ice across the bedrock surface "caused fracturing or jointing in the rock and left scratches or striations on the rock surface. The lower part of stratigraphic unit 25, which made up the upper layer of rock over the downstream portion of the foundation area was badly jointed or fractured and was removed with a bulldozer in places without blasting. Drag joints also occurr ed in stratigraphic unit 24 over parts of the foundation area.

These were nearly vertical at the top of the stratigraphic unit but curved in the lower part of the unit to nearly horizontal. These joints in unit 24 also were very tightly filled with glacial till material that apparently was forced into the joints by the ice as the joints were formed. Two sets of glacial striae were exposed on the rock surface over approximately the downstream third of the foundation area before rock excavation was commenced. One set had a strike around S50°W (Malone glaciation) and the other around S9°E (Fort Covington glaciation)" (U.S. Army, Ref. 14).

No definite evidence of faulting was found during the geophysical survey, however, borings made in 1941 (D-1302, D-1303, D-1304 and others) indicated a fault upstream from the limits of the lock walls. The fault zone is around 200 feet wide and diagonally crosses the canal centerline between approximately Sta. 533+50 and Sta. 539+50. It strikes about N56°E and probably dips very steeply to the northwest. Beds are vertically displaced about 35 feet, with the upthrow side on the northwest. The rock at and adjacent to the fault is badly brecciated and fractured. Boring C-701309 was drilled on the north side of the lock in the area of the fault zone and showed 54.5 feet of dolomite bedrock with numerous high angle and low angle fractures healed with calcite.

Two major joint sets occur at the site, and a few joints belonging to a third set were also found (see below):

Joint Set	Strike	Dip
1. Major	N37°E to N56°E	Very steep to near vertical
2. Major	N80°W to N90°W	Very steep to near vertical
3. Minor	N10°W	Very steep to near vertical

The bedrock is virtually unweathered except for the upper 10 feet of rock where some yellowish-brown or rust-colored staining was observed along partings or bedding planes.

In the foundation rock of Snell Lock "zones of leached rock and small cavities or solution voids are widely distributed in certain stratigraphic zones ... These are mostly parallel to the bedding. The leached zones range in thickness from 0.1 inch to about 3.0 feet and in degree of leaching from a slight change in color to soft, earthy-appearing rock exhibiting honey-combing by solution and high absorption. The cavities range in thickness from about 0.5 inch to about 7 inches and were formed by solution of the rock. Most of the leached zones and cavities are in stratigraphic units 16, 15, 14 and 13 although they were encountered in nearly all the stratigraphic units that were penetrated by explorations in the foundation area. Some of the leached zones and cavities are persistent under a fairly large portion of the foundation area. One such persistent zone is about 2 feet below the top of stratigraphic unit 16. This zone was evidenced in many of the cores as a leached or a soft absorbent zone, or as a cavity. Unit 15 contains cavities and is composed of soft, absorbent, honey-combed rock or contains zones of soft, absorbent, honey-combed rock under most of the foundation area. Unit 14 also contains persistent zones that are absorbent and that are honey-combed by solution" (U.S. Army, Ref. 14).

The "downhole" geophysical test performed in boring C-701305 showed a very low bedrock vertical velocity in the upper 10 feet, probably indicating considerable solutioning

and/or weathering. However, it also suggested that "the individual cavities do not have significant lateral extent" (U.S. Army, Ref. 15).

3.4.2 Vicinity, Eisenhower "Twin" Alternative

Figure 5 shows a top of rock contour map based on the results of the 1970 geophysical survey. It can be seen that the bedrock topography is generally more gentle than at the Snell site. The bedrock surface is nearly horizontal to the west and becomes a series of rather broad ridges and valleys trending northeast-southwest from south of boring C-681212 eastward to boring UDC-681201. "There is one steep ridge in the bedrock midway between drill holes C-681203 and C-681205 trending approximately N20°E. The ridge is fairly abrupt with the western side approximately 20 feet higher than the east" (U.S. Army, Ref. 16).

Beneath Eisenhower Lock the rock strata "are very nearly horizontal but have a slight general dip northwestward and contain small undulations. The strike and the direction of dip of the strata varies in accordance with the undulations. The amount of dip for the most part is less than 1°43' or 3 feet per 100 feet" (U.S. Army, Ref. 13).

Three major joint sets occur at the site, as follows:

Joint Set	Strike	Dip
1. Most prominent	N8°W to N20°W	Very steep to near vertical
2. Major	N26°E to N43°E	Very steep to near vertical
3. Major	N70°E to S85°E	Very steep to near vertical

The bedrock is virtually unweathered except for the upper 5 feet where some yellowish-brown or rust-colored staining was observed along partings.

In the foundation rock of Eisenhower Lock "thin zones of leached rock and small solution voids or cavities are widely distributed in certain stratigraphic zones ... They apparently are more common in the downstream portion of the foundation rock than in the upstream portion. Those which are most persistent occur about 3 feet below the top of stratigraphic unit 13, at the top of stratigraphic unit 15, near the bottom and at the top of unit 16, and near the bottom and near the middle of unit 25. They are the result of leaching and solution by ground water and, for the most part, are parallel to the bedding. The leached zones range in thickness from 0.1 inch along bedding planes or partings to about 7.8 inches and in degree of leaching from just a slight difference in color to earthy-appearing rock exhibiting high absorption. The cavities range in thickness from about 0.1 foot to 0.9 foot" (U.S. Army, Ref. 13).

The geophysical survey found no definite evidence of faulting.

3.4.3 Vicinity, High-Lift Alternative

On Plate 14, the line showing approximate top of bedrock is taken from a map prepared by the Buffalo District prior to the 1970 geophysical survey. The areas covered by the survey lie too far beyond the High-Lift alignment to be of much help in more accurately defining the true top of bedrock. Rock appears to come closest to the ground surface (El 140 feet) beneath the Grass River around Sta. 550+00. This roughly

corresponds to the bedrock high found at the Snell site. To the west the bedrock slopes gently downward to about El 100 feet before rising again to El 140 feet at Lake St. Lawrence.

Borings and water wells along the alignment provide no information on other structural features, such as jointing, solutioning, or faulting.

3.4.4 Vicinity, Iroquois-Point Rockway Alternative

The best data available on the bedrock structure come from the 1941 borings made along the originally proposed alignment for Iroquois Dam, about 3,000 feet downstream of the present dam. All these borings lie in or near the upstream guide wall area of the proposed site (see Plate 15); no borehole data is available for the lock or downstream guide wall areas. Geophysical data from the 1940-41 survey similarly is limited to the upstream guide wall. No geophysical investigations were carried out at the site during the 1970 program.

On the east near boring D-1046, the bedrock surface starts as a high at about El 210 feet and slopes downward to the northwest to El 160 feet near boring D-1043. The slope is almost 8 feet per 100 feet along this section. The approximate top of rock line along Profile D-D (Plate 16) is based on the rock contours provided in Ref.15.

The boring logs do not provide enough information to determine the strike and dip of the bedding. It may be assumed that the strata follow the regional trend and are either flat-lying or dipping gently at 5° or less to the northwest. In general, the rock appears to be only slightly weathered with

some moderately to badly broken zones. No joint sets have been defined, but boring D-1296 indicates that the rock is broken along numerous 60° joints.

Evidence of faulting was discovered in borings D-1050 and D-1053, located about 1,400 feet northwest of the upstream guide wall (Plate 15). Dr. Charles Berkey examined rock cores from these borings in 1944 and determined that "no great amount of movement is indicated, but a strongly stressed condition resulting finally in excessive shattering of the rock". He concluded that "the best that can be said for this Iroquois occurrence is that two of the borings on this site show the existence of typical stress crush zone material which is judged to represent faulting. But the course or orientation of the line of faulting or of the crush zone is not yet determined" (Berkey, Ref. 2).

Other evidence of possible faulting farther east shows up in boring D-1043 (Plate 16) where a cemented breccia zone is described as occurring at about El 134 feet.

3.5 Ground Water

A good deal of ground water information is available at both the Snell "Twin" and Eisenhower "Twin" sites from data collected during construction of the present locks and also from the 1968 and 1970 boring programs. At the High-Lift site, most of the information comes from water well records compiled by Trainer and Salvas (Ref. 9). No basic ground water data is currently available for the Iroquois-Point Rockway site.

3.5.1 Vicinity, Snell "Twin" Alternative

During excavation work for Snell Lock, piezometers were installed in the marine clay overburden and measurements of water levels were taken. At first the piezometric levels registered 7 to 9 feet bel w ground surface. As excavation progressed, the level adjacent to the lock area dropped, and then rose again after the excavation slope was backfilled.

Prior to construction, water levels were measured in those borings drilled into bedrock and proved to be lower than the levels found in the borings confined to overburden materials. These "bedrock levels" averaged 26 feet below the existing ground surface (or 46 to 72 feet above the bedrock surface). They were about El 158 feet, very close to the level of Grass River, and fluctuations in the ground water levels tended to reflect level changes in Grass River. Dewatering during construction lowered the piezometric level in these borings to top of rock or lower. The levels completely recovered after the lock area was flooded preparatory to opening the lock and canal to navigation.

In the 1970 boring program, water levels were recorded in each hole as drilling progressed. Boring C-701303 (Plate 8) showed the piezometric level to be at the ground surface as the hole was advanced through the overburden of backfill and marine clay. Once the hole went into bedrock, the water level dropped 51.2 feet to about El 154 feet, very close to the level of Grass River. To the east along Profile A-A (Plate 8) in boring

C-701307, the piezometric levels in overburden and bedrock were very close (13.6 feet and 12.4 feet below ground surface, respectively). The bedrock piezometric level was at El 155 feet, again close to the level of Grass River. Farther east in boring C-701305, the water level rose from 12.8 feet below ground surface (hole in overburden) to 4.7 feet (hole in bedrock). The bedrock piezometric level was again El 155 feet.

In boring C-701305, hydrogen sulfide gas was encountered while drilling through the bedrock, approximately between Units 9 and 6. Gas had been previously found in the bedrock in hole GR-23 (Plate 4) during construction in 1955 and a water sample was taken at that time for chemical analysis. The results were as follows:

Iron	2.5 ppm
Sulphates	639 ppm
Chlorides	70 ppm
pH	7.3

3.5.2 <u>Vicinity, Eisenhower "Twin" Alternative</u>

Prior to construction of Eisenhower Lock, water level measurements were taken in boring D-1173, located on the north side of the lock near the upstream pintle (Plate 11). The hole was 70 feet deep, terminating in the till and the water level in the hole was considered representative of the ground water level in the overburden across the top of the ridge. The level fluctuated between 11 and 17 feet below the ground surface (El 245 and 251 feet, respectively). Test pits dug on the upstream and downstream sides of the ridges filled with water to within

4 to 6 feet of the ground surface. As at Snell Lock, the water level adjacent to the lock area dropped during excavation work and then rose again after backfilling.

Borings in bedrock prior to construction showed water levels about 80 to 90 feet (El 160 to 170 feet) below the level in D-1173. These levels were about 20 to 30 feet above the bedrock surface, and fluctuated with changes in the level of the St. Lawrence River. The levels dropped as excavation work progressed and subsequently rose after backfilling was completed.

During the 1968 boring program, water levels were taken in the holes as drilling progressed through overburden into bedrock. In borings UDC-681202, C-681203 and C-681205 (Plate 13), the water levels recorded in the overburden ranged from about 0 to 5 feet below ground surface. Once the holes penetrated into the bedrock, the water levels dropped to approximately El 173 feet, some 30 to 40 feet above the bedrock surface. This is very close to the pre-construction water levels for holes in bedrock.

A slight odor of hydrogen sulfide was detected in the water in the bedrock during construction, but no chemical analysis of the ground water at the site was made.

3.5.3 Vicinity, High-Lift Alternative

The available data from borings and wells along the proposed alignment are plotted on Plate 14. The water levels shown were obtained from Trainer and Salvas (Ref. 9). Because of the limited amount of information in the area, it is diffi-

cult to generalize to any great extent on the localized ground water regime.

For the greatest length of the alignment - north of Grass River from Sta. 580+00 upstream to about Sta. 360+00 - the water table slopes to the south and southeast toward Grass River. From Sta. 360+00 to Lake St. Lawrence, the water table slopes toward Robinson Creek. Ground water levels are highest in March or April and lowest in August or September. Recharge of the ground water is greatest in the early spring and late fall.

Wells completed in overburden show a range of water levels of from 5 to 12-1/2 feet below ground surface. The water levels in those wells which extend into the bedrock are generally deeper and show a much wider range - 17 to 67 feet below ground surface.

3.5.4 Vicinity, Iroquois-Point Rockway Alternative

The borings shown on Profile D-D on Plate 16 were drilled in the St. Lawrence River, and no information was recorded concerning piezometric levels in either the overburden or the bedrock. Similarly, no water levels are given for the test pits (see Plate 15) dug on land in the proposed lock area. There are no indications of any wells existing along the proposed alignment. It can only be assumed, therefore, that the ground water regime at the site may be analogous to that found at the Snell "Twin" and Eisenhower "Twin" alternative sites, since the geologic setting at all three sites is similar glacial till and marine clay overlying dolomite bedrock.

4. SUBSURFACE EXPLORATIONS

4.1 Drilling Programs

In 1895, the Deep Waterways Commission was appointed to report on all possible routes for a deep waterway connection between the Great Lakes and the Atlantic Ocean, and since then several subsurface exploration programs have been carried out. Exploratory drilling began in 1898 and has continued off and on through the years until the completion of the present Snell, Eisenhower and Iroquois Locks in 1958. For a study of additional locks proposed in the vicinity of these three sites, further drilling work was done in 1968 (near Eisenhower Lock) and 1970 (near Snell Lock) but no investigations were performed for the Iroquois-Point Rockway or High-Lift alternatives.

Plates 3 to 7, 9 to 12, 14 and 15 show the locations of boreholes and test pits in the vicinity of the alternative sites. Detailed information on the exploratory work performed from 1898 to 1958 is given in Refs. 10 through 17.

4.1.1 Explorations Prior to 1968

The first set of borings (100-series) was performed in 1898-99 for the Board of Engineers on Deep Waterways. The borings were apparently wash borings that were made using a "Sullivan boring machine". Those borings drilled in the vicinity of the present Snell and Eisenhower Locks indicate a considered canal alignment differing somewhat from that of the present Wiley Dondero Canal. None of these borings were

drilled at the present lock sites or in the immediate area of the proposed "Twin" alternatives. Similarly, the borings made in the Iroquois-Point Rockway area lie outside the proposed site for the new lock.

Investigations by the St. Lawrence Waterways Joint Board of Engineers in 1925-26 in connection with studies of various plans for the development of the St. Lawrence River included four borings within the excavation area for Snell Lock; one boring in the general vicinity of Eisenhower Lock; and one boring within the upstream guide wall area of the proposed Iroquois-Point Rockway site. A 1932 boring program included two more borings within the excavation area of Snell Lock. These borings were given a 200-, 400- and P-300 series designation.

In 1941, the St. Lawrence River District, United States Engineer Department, carried out a large-scale exploration program to determine the overburden and bedrock conditions for the purpose of locating the lock structures and obtaining information for design. The program consisted of drilling in overburden and bedrock; excavation and sampling of auger holes and test pits; probing in soft overburden; and the determination of bedrock elevations and study of general soil conditions by the seismic method. The boring series was designated D-1000. Numerous borings are located within the general vicinity of the present Snell and Eisenhower Locks. Ten borings lie within the proposed channel area of the High-Lift alternative but none within the lock area itself. The borings

at Iroquois-Point Rockway indicate a considered lock and canal alignment along Whitehouse Creek quite different from the present location of Iroquois Lock farther to the west on the Canadian side of the river. Some borings made at the originally proposed location for Iroquois Dam fall within the upstream guide wall area of the proposed alternative lock site, and six of them are shown in profile on Plate 16.

Just prior to construction in 1954-55, further explorations at Snell and Eisenhower Locks were performed by the Massena Area Office, U.S. Army Engineer District, Buffalo, to obtain more definite and detailed site specific subsurface information for the design and construction of the locks. Borings were designated GR- (for Grass River area), RB- (Robinson Bay), etc. Many of these borings lie within the proposed "Twin" lock areas. From 1953 to 1958, over 130 borings (numbered 601 to 693, and 1200 to 1242) were drilled along the alignment of the present Iroquois Lock and fall outside the study area of the Iroquois-Point Rockway alternative.

During the construction of Snell and Eisenhower Locks, foundation explorations (on a closer spacing than before) were performed to determine excavation grades and the need for foundation treatment. These borings continue the GR-, RB-, etc. series.

4.1.2 Explorations in 1968 and 1970

For a feasibility study of additional locks along the St. Lawrence River, the U.S. Corps of Engineers, Buffalo District, carried out two drilling programs with a total of 23 borings in

the vicinity of the Snell and Eisenhower Locks. All the drilling work was performed by the Corps of Engineers, Mobile District. No borings were made along the proposed alignments of the High-Lift and Iroquois-Point Rockway alternative.

4.1.2.1 Eisenhower "Twin" - 1968

The 12 borings drilled in this zone lie within or very near the lock and downstream guide wall areas of the proposed "Twin" (see Plates 10 and 11). These holes with their locations and other pertinent data are listed in Table 2, and the detailed geologic logs are attached to this report. Plate 13 shows a geologic profile through four of these borings.

All holes were drilled vertically using a Failing 314 CD-38 drill rig. The drilling took place from May 25 to November 1, 1968. Overburden was cased using 4-inch or 6-inch casing whenever possible and NX casing set whenever bedrock was encountered. In overburden, the holes were advanced using a 5-inch flight auger and when appropriate, the hole was cleaned using a 6-inch side-jetted fishtail. Soil sampling was performed with a 2-inch split-spoon sampler, 3-inch Shelby tube, 4-inch Denison sampler and several double tube core barrels with 2-3/4" x 3-7/8", 4" x 5" and 6" x 7-3/4" size drill bits. Coring in bedrock was done with an NW-size double tube core barrel and an M-series diamond bit. Figures 6 and 7 show photographs of typical rock cores recovered during the drilling program.

Twenty-three undisturbed samples of the marine clay were obtained from borings UDC-681201 (14 tubes) and UDC-681202 (9 tubes), by means of a 3-inch Shelby tube sampler.

The depth of overburden as determined from the borings ranged from 61 feet to 110 feet, averaging around 90 feet across the area. Of the 11 holes drilled into the bedrock, 8 of them continued at least 100 feet below top of rock. Rock core recovery averaged about 96%.

Borehole photographs were taken in borings C-681208 and C-681210, and the logs are attached to this report.

Pressure testing in bedrock was performed in 10 of the 12 borings; procedures and results are discussed in Section 5.3.1.

Upon completion of all drilling and testing, the holes were backfilled with a neat cement grout to the top of rock and from there to the ground surface with sand or a sand/bentonite mixture.

4.1.2.2 Snell "Twin" - 1970

Of the 11 borings drilled in this program, 10 lie within the lock area of the proposed "Twin" and one (C-701309) is located on the north side of the present Snell Lock (see Plate 4). These holes with their locations and other pertinent data are listed in Table 3, and the detailed geologic logs are attached to this report. Plate 8 shows a geologic profile through three of these borings.

The drilling was done from May 12 to July 23, 1970. All holes were drilled vertically, and the drill rig, samplers and other equipment used were the same as described in Section 4.1.2.1. Figures 8 and 9 show photographs of typical rock cores recovered during the drilling.

Eighteen undisturbed samples of the marine clay were taken from borings UC-701306 (16 tubes) and UD-701308A (2 tubes) using a 3-inch Shelby tube sampler.

The depth of overburden in the proposed "Twin" lock area ranged from 42.9 feet to 76 feet, for an average of about 60 feet. Boring C-701309, located on the north side of the lock, had 91.1 feet of overburden. Ten of the borings were continued into the bedrock a maximum of 102 feet, and rock core recovery averaged over 97%.

Borehole photographs were taken in borings C-701303 and C-701306, and the logs are attached to this report.

Pressure testing in bedrock was performed in 10 borings; procedures and results are discussed in Section 5.3.2.

As at the Eisenhower site, backfilling of holes was done with a neat cement grout in bedrock, and sand, or a sand/bentonite mixture, in the overburden.

4.2 Geophysical Surveys

Two separate geophysical surveys have been carried out in connection with studies for the St. Lawrence Seaway Project. The first survey, conducted prior to construction in 1940-41, covered the entire length of the project from Chimney Island (northeast of Ogdensburg) to Cornwall Island, near the mouth of the Raquette River. The seismic refraction method was used, both on land and in the river. The latest survey was conducted in 1970 and was limited to the general area proposed for the "Twin" lock sites south of Snell and Eisenhower Locks. Seismic

refraction and electrical resistivity were employed in this investigation.

4.2.1 Seismic Exploration, 1940-41

The seismic investigations were conducted by the St. Lawrence River District of the U.S. Army Corps of Engineers for the general purpose of obtaining data between drill holes to minimize the amount of drilling needed. The work was performed between November 1940 and October 1941, with a 2 month suspension in March and April due to frost conditions. An array of detectors (usually three) was placed on the ground surface and charges of dynamite were exploded at various distances from the detectors. An effort was made to conduct the survey on the same type of overburden. For work on the river, special waterproof equipment was designed. In quiet water the detectors and charges were set using floats; in swift water special procedures had to be worked out (Ref. 11).

From the time-distance graphs obtained by plotting the seismic data, depths to bedrock were computed and top of rock contour maps were drawn. In general, the correlation between seismic information and drilling data was found to be quite satisfactory, except for one area along the proposed alignment for the Point Rockway Canal where comparatively low velocity (5000 feet per second) material originally thought to be clay or till was discovered to be shallow and fractured rock. Another area, near the Massena Power Canal, showed erratic readings and made precise interpretation difficult. This was the result of artificial conditions created in the area by the dumping of spoil from the excavation of the power canal.

Frozen ground also led to uncertainties in interpretation, particularly in the Wiley-Dondero Canal area, by giving abnormally high velocity values for the overburden.

The average velocities for the different materials encountered in the survey area are given in Table 4.

4.2.2 Geophysical Survey - 1970

The geophysical explorations were conducted by the Missouri River Division (MRD) of the U.S. Army Corps of Engineers in order to better define bedrock conditions between boreholes and locate any possible faults in the area south of the present Snell and Eisenhower Locks. The field work was carried out from June 1 to June 24, 1970, using conventional surface seismic refraction methods with reverse shooting, electrical trenching, and vertical electrical sounding with the Wenner electrode configuration. The geophysical equipment was supplied by the MRD Laboratory. Survey coverage was as follows:

Geophysical Method	Snell	Eisenhower
1. Land seismic refraction	7,700 lineal feet	9,350 lineal feet
2. Underwater seismic refraction	1,760 lineal feet	1,100 lineal feet
3. Downhole survey	117 feet in boring C-701305	-----------------
4. Resistivity trench	-------------------	E-W line with 13 stations
5. Vertical resistivity soundings	5	4

Seismic lines were run both on land and in water; resistivity stations were only on land. All shot points and stations were surveyed by a crew from the Buffalo District, and lithologic control was provided by a number of drill hole logs at both sites.

The average seismic velocities and electrical resistivity values for the various materials encountered are shown in Table 5. Based on these data, depths to bedrock were computed and top of rock contour maps were produced for each site (Figures 3 and 5). In addition, a till isopach map was prepared for the Eisenhower site (Figure 4).

The survey results indicated that little if any till would be encountered during excavation at the Snell site, whereas a considerable thickness (50 to 110 feet) could be found at the Eisenhower site. The velocity of the till at both sites indicated that it would be marginally rippable.

The survey also showed that the configuration of the bedrock surface at the Eisenhower site was generally flat along the west side but had broad N-S trending valleys and ridges to the east. A buried ridge with an abrupt slope was found trending about N20°E through the area near the eastern end. At the Snell site, a bedrock high (about El 150 feet and sloping west, north and east) was found at the SW corner of the area. The bedrock surface is cut by two NE trending channels nearly in the center of the areas.

No definite evidence of faulting was found.

5. FIELD AND LABORATORY TESTING

In the various drilling programs performed since 1895, extensive sampling and testing of the overburden and bedrock materials were done in the general vicinity of three of the four alternative sites. No data is currently available for the area of the High-Lift alternative.

5.1 Soil Testing

For the period prior to 1968, detailed soil data is available from the 1941 and 1954-55 exploration programs. Along the alignment for the 1941 proposed Point Rockway Canal, soil samples were taken with a 2-inch diameter "dry sampling tube" and, for undisturbed samples of clay, a specially constructed spoon which provided samples 4-5/8 inches in diameter. The clays were tested for moisture content, liquid limit, plastic limit, specific gravity, consolidation and quick shear. For a description of sampling and testing procedures, see Ref. 12.

During the 1941 drilling program in the vicinity of Eisenhower Lock, the overburden was sampled using 2-inch split-spoon samplers and NX-size double tube core barrels. The recovered samples were used for classification, moisture content determinations and mechanical analysis tests. In the 1954-55 program, soil samples were recovered by: (1) drive sampling with 2-inch split spoon samplers with brass liners, (2) washing, and (3) coring with NX and 6-inch double tube core barrels. Testing included a full range of identification tests (grain size, Atterberg limits, etc.) as well as triaxial

compression tests. See Ref. 13 for detailed sampling procedures and test results.

During the 1941 program at Snell Lock, 1-1/2 inch and 2-inch split-spoon samplers were used to obtain soil samples for classification, moisture content determinations and mechanical analysis tests. The M.I.T. sampler was used to obtain undisturbed samples of clay material for consolidation and shear tests. In the 1954-55 program, 2-inch split-spoon samplers with brass liners were used to recover material for classification tests and moisture determinations. Undisturbed samples for strength tests were obtained with 5-inch Shelby tube samplers. Laboratory testing of the undisturbed samples included determination of moisture content, liquid limits, plastic limits, and density, and triaxial compression tests. The bottom portion of seven (7) of the soils borings was cored with a 6-inch core barrel. The core samples were used for classification and moisture determinations, and some cores were placed in sheet metal tubes for future reference. See Ref. 14 for detailed sampling procedures and test results.

5.1.1 Eisenhower "Twin" - 1968

As mentioned in Section 4.1.2.1, during the 1968 program, soil sampling was performed with a 2-inch split-spoon sampler, 3-inch Shelby tube, 4-inch Denison sampler and several double tube core barrels with 2-3/4" x 3-7/8", 4" x 5", and 6" x 7-3/4" size drill bits. Laboratory testing was done by the North Central Division, U.S. Corps of Engineers, Chicago, Illinois.

In boring UDC-681201, fourteen (14) Shelby tube samples were recovered in the marine clay. The tests performed on this material and the test results are shown in Table 6. The range in values of several important characteristics are:

Liquid Limit (%)	33 to 64
Plastic Limit (%)	17 to 27
Dry density (pcf)	58.3 to 87.2
Water content (%)	34.6 to 70.0

Nine (9) Shelby tube samples of the marine clay were taken from boring UDC-681202 (see Plate 13). Table 6 summarizes the test results and shows the following ranges:

Liquid Limit (%)	45 to 57
Plastic Limit (%)	19 to 25
Dry density (pcf)	61.7 to 76.7
Water content (%)	44.8 to 64.8

In boring C-681206, the backfill along the south side of Eisenhower Lock was sampled using 4" x 5" double tube core barrel. Table 6 shows the test results. Thirty-one (31) of the samples were grouped into eight (8) test series in order to obtain strength envelopes from the triaxial test results. The material is basically silty sand and gravel and shows the following range of values:

Fines content (%)	23 to 44
Liquid Limit (%)	13 to 21
Plastic Limit (%)	10 to 14
Dry density (pcf)	129.9 to 153.3
Water content (%)	2.9 to 9.3

5.1.2 Snell "Twin" - 1970

The procedures and equipment used to sample the overburden are the same as described in Section 4.1.2.1. Laboratory testing was done by the North Central Division, U.S. Corps of Engineers, Chicago, Illinois. The tests performed and their results are shown in Table 7.

In boring UC-701306, sixteen (16) 3-inch diameter Shelby tube samples were recovered in the marine clay. The test results showed the following range of values:

Liquid Limit (%)	40 to 59
Plastic Limit (%)	19 to 26
Dry density (pcf)	61.9 to 78.5
Water content (%)	43.4 to 64.9

Two (2) Shelby tube samples of the marine clay were taken from boring UD-701308A, and the test results showed:

Liquid Limit (%)	58 to 60
Plastic Limit (%)	22 to 23
Dry density (pcf)	74.3 to 89.3
Water content (%)	32.4 to 47.3

5.2 Rock Testing

During the 1941 drilling program for the proposed Point Rockway Canal, rock cores of the dolomite bedrock were obtained and tested to determine whether the rock from the canal excavation was suitable for concrete aggregate.

Rock cores were also taken in the vicinity of the Eisenhower and Snell Locks in the various drilling programs performed prior to 1968 in these areas. The rock was described and classified, but no record of any type of testing is available.

5.2.1 Eisenhower "Twin" - 1968

Rock cores during the 1968 program were obtained with an NX-size double tube core barrel. Selected samples from borings C-681210 and C-681211 were sent to the Ohio River Division Laboratories (ORDL) for testing. The strength tests performed included compressive strength, direct shear, sliding friction, bond shear and triaxial compression. In addition, moisture contents and unit weights were determined and petrographic analyses were made on twelve (12) samples. Table 8 shows a summary of the test results. The water content measurements were quite low (less than 1% in most cases) and it was questionable whether they were truly representative of in situ conditions. Unit weight values ranged from a high of 175.3 pcf for dolomite to 132 pcf for a sample of gypsum. Sample 1A from boring C-681211 was tested to determine Poisson's Ratio, and the recommended average value was found to be 0.075. See Ref.16 for a detailed description of testing procedures and results.

5.2.2 Snell "Twin"-1970

During the 1970 drilling program, rock cores were obtained with an NX-size double tube core barrel. Selected samples from borings C-701302, C-701303 and UC-701306 were sent to ORDL for testing. Strength tests included unconfined compression, direct shear, bond shear, sliding friction (rock on rock) and triaxial compression. Moisture contents, specific gravity and unit weights were also determined, and petrographic analyses were made on twelve (12) samples. Table 9 shows a summary of

the test results. The results of the direct shear tests were considered somewhat questionable because the strength of the samples sometimes exceeded the crushing strength of the hydrostone. Water contents were very low - less than 1% in most cases. Unit weights were very similar for all samples tested, ranging from a high of 178.2 pcf for a sample of highly argillaceous dolomite to 173.4 pcf for a typical dolomite. Poisson's Ratio was determined on samples 4 and 6 from boring C-701303, and the recommended average values were 0.16 and 0.26, respectively. See Ref. 17 for a detailed description of testing procedures and results.

5.3 Pressure Testing

There are no records to indicate that water pressure testing of the bedrock was done during the 1941 drilling program along the alignment of the proposed Point Rockway Canal.

In the 1954-55 drilling program at Eisenhower Lock, fifteen (15) of the borings in bedrock were pressure-tested with water using a 5-foot double packer to determine permeability or leakage conditions in the bedrock. During construction in 1956, seventeen (17) additional foundation exploration holes were pressure-tested, again using 5-foot double packers. Because most of the 1956 borings showed flowing water under artesian pressure, flow measurements were substituted for pressure tests in other holes. In total, flow measurements were made on fifteen (15) holes including eight (8) of the holes that were pressure-tested. See Ref. 13 for a detailed description of test procedures and results.

In the 1954-55 drilling program at Snell Lock, nineteen (19) of the exploratory holes in bedrock were pressure-tested with water using a 5-foot double packer. Additionally, a pumping test was performed on hole GR-16, with four other holes serving as observation wells. Permeability tests were performed in five (5) borings. During construction in 1956, pressure tests were performed in seven (7) of the foundation exploration holes. A single packer was used to test a section extending from 20 feet below top of bedrock to the bottom of the hole. See Ref. 14 for a detailed description of test procedures and results.

5.3.1 Eisenhower "Twin" - 1968

Pressure testing in bedrock was performed in ten (10) of the twelve (12) borings drilled in 1968. Both a single packer and a 5-foot double packer set-up were used. The maximum gage pressure was limited to 50 psi and was adjusted accordingly so that the pressure in the zone being tested would not exceed one (1) psi per foot of overlying material. The test results are listed in Table 10.

Of the 151 tests performed, 96 showed water losses greater than 10 gpm. Over 50% of the high loss zones occurred within stratigraphic Units 13 to 16. Sections of Unit 13 were included in nearly 30% of these zones, however, it should be noted that Unit 13 is by far the thickest unit (24.4 feet thick) in the area and it was involved in many more pressure tests than any other single unit.

Fifty (50) tests showed water losses greater than 20 gpm.

Units 13 to 16 accounted for nearly two-thirds of the high loss zones, with Unit 13 included in over 40% of them.

The maximum water loss of 32 gpm occurred when testing the bottom 19 feet of boring UDC-681201. For a 5-foot zone, the maximum was 27 gpm within Units 13 to 16 in boring UDC-681202. Forty (40) tests showed no water loss.

5.3.2 Snell "Twin" - 1970

In the 1970 drilling programs, ten (10) of the eleven (11) borings were pressure-tested in bedrock. The same equipment and test procedures were used as described in Section 5.3.1. The test results are listed in Table 11.

In the 161 tests performed, 63 showed water losses greater than 10 gpm. Units 13 to 16 accounted for more than 60% of the high loss zones, with Unit 13 included in over 20% of them.

The maximum water loss recorded was 19.5 gpm for a 5-foot zone between Units 25 and 26 in boring C-701303. Sixty (60) tests showed no water loss.

6. GEOTECHNICAL ASPECTS

The geotechnical aspects for the design of the four proposed alternative sites can not be discussed in detail since no extensive site specific information is available. There is, however, extensive information regarding subsurface conditions at the sites of the existing Snell, Eisenhower and Iroquois Locks. The proposed sites for the Snell and Eisenhower "Twin" Locks are in close proximity to the existing locks and the locations of several previously drilled borings are within the proposed alternative alignments and therefore can be used in making a reasonable assessment of subsurface conditions. In

the vicinity of Snell Lock, about 15 borings exist along the alignment of the proposed "Twin" and about 25 borings for the Eisenhower site. Practically no useful boring information is available for the High-Lift alternative; there is some geophysical data and local water well information, and this has been used in determining subsurface conditions. At the Iroquois site, about 15 previously drilled borings can be located within the proposed alternative alignment and almost all of these are located at the upstream end. In addition, the information obtained from these borings is very sketchy and very little detail is given regarding the materials. Nevertheless, based on this limited information and experiences others have had in previously constructed projects in the vicinity, certain general inferences can be made regarding the alternative sites.

During the construction of Snell, Eisenhower and Iroquois Locks, difficulties were encountered which were directly attributable to the foundation materials. A general description of the subsurface conditions at the four alternative sites has been given in previous paragraphs. It can be seen that there are basically three materials, two of which caused most of the difficulties during the construction, namely; the marine clays and the glacial tills. Dolomite, the underlying bedrock, created few problems. Burke (Ref.3), Armstrong and Burnett (Ref. 1) and Haines and Olson (Ref. 6) describe in detail the design and construction problems encountered during construction of the St. Lawrence Seaway.

The difficulties caused by the marine clays were a result of their weak strength and extreme sensitivity. The design and construction of the canal slopes of major cuts necessitated extensive investigation and testing programs. Resulting cut slopes varied from 1V to 2H in areas where depth of cuts or thickness of clay was shallow to 1V to 10H where relatively deep cuts were required. In areas where dikes were constructed over the clay, they had to be wide and flat sloped for stability purposes. The disposal of the extremely sensitive clays also created a problem. When reworked, the clays became "soup" and it was necessary, therefore, to provide extensive spoil areas to allow the clay to be deposited to shallow depths and very flat slopes. For the same reason, it was very difficult to have construction traffic on the clays.

The problems associated with the glacial tills were basically those of excavation, seepage and trafficability. A detailed description of the difficulties during design and construction is given by the previously mentioned authors and by Cleaves (Ref.4). Excavation problems were caused by the compact to highly compact nature of the basal till (Malone) which also contained boulders. In wintertime, it was necessary to blast the till which became frozen. The presence of sand and silty zones within the tills further increased the difficulties because these materials became "quick", bogging down excavation equipment and causing excessive seepage and stability problems in cuts. In addition, the upper tills, which are less compact, became impassable during seasons of thaw and high

rainfall. It is apparent, therefore, that prior to final design, the location and extent of the clays and tills needs to be defined and a final assessment be made as to the viability of the sites. At that time the exact alignment and location should be made for the proposed channels, guide walls and locks. The determination of design parameters will be required also for utiliation in stability and seepage analysis and in evaluating temporary support systems and trafficability.

Since the proposed sites are within Seismic Zone No. 3, dynamic analyses will be needed for the design of proposed structures and cut slopes. Dynamic parameters for the rock and soil types will have to be established and an examination and analysis of seismic data will be required for the selection of a Maximum Credible Earthquake, a Design Earthquake and a Design Accelerogram.

To obtain the aforementioned information, an extensive subsurface exploration and testing program should be carried out at the four sites. These programs should include: the drilling of vertical and inclined holes; obtaining disturbed and undisturbed samples of overburden; core retrieval in rock; seepage testing in overburden and water pressure testing in rock; digging of test pits and trenches, geophysical surveys including shear wave measurements (i.e., cross-hole methods); and laboratory testing of rock and soil samples. It also will be necessary to search for possible sources of construction materials especially fine and coarse aggregate. These probably can be found in the sand and gravel deposits in the tills.

Consideration should be given to the installation of a seismological network for the monitoring of macro- and/or micro-seismic activity and instrumentation for monitoring ground water.

Laboratory testing should include classification and engineering properties tests such as: compaction, permeability, consolidation, direct shear and triaxial compression. Dynamic testing should include simple cyclic shear, cyclic triaxial compression and resonant column.

7. CONCLUSIONS

A review and assessment of the information presented above indicates that construction of the alternative locks and channels at the proposed locations appears to be geotechnically feasible. It is apparent that whichever is the selected location, substantial additional geologic, geophysical and geotechnical investigations will be required prior to the final design. These investigations should include extensive site specific subsurface exploration, field and laboratory testing of soil and rock samples, geophysical surveys, hydrogeologic studies and seismological (dynamic) investigations.

Based on the subsurface conditions determined from available data, it is reasonable to assume that similar bedrock conditions will be revealed by future investigations. Since the surficial deposits are basically glacial in nature, it can be expected that erratic soil conditions will exist throughout the area. However, the major soil types will probably be similar to those which have been encountered in the past.

A major advantage in the future design and construction of project structures will be the experiences gained during the

original construction of the Seaway. Knowing in advance in which materials problems can be expected (i.e., the very soft marine clays and the extremely dense glacial tills), and to have design and construction solutions to these problems is a great advantage for any project.

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Table 1
Stratigraphic Units in Bedrock

SYSTEM	STAGE	GROUP	UNIT	THICK-NESS	DESCRIPTION
				0 to 75	MARINE CLAY Borderline Clay (CL-CH) : Generally classified as Fat Clay (CH) with a silty texture; soft to very soft; moist to wet; dark gray to bluish-gray.
PLEISTOCENE	WISCONSINAN			0 to 110	FORT COVINGTON (Glacial Till) Lean Clay to Sandy Clay (CL-SC) : Contains gravel, cobbles and boulders embedded in clay; generally very stiff to hard; dry to slightly damp; gray to brownish-gray.
					MALONE (Glacial Till) Lean Clay to Sandy Clay (CL-SC) : Contains gravel, cobbles and boulders embedded in clay; generally very stiff to hard; dry to slightly damp; gray to brownish-gray.
ORDOVICIAN		BEEKMANTOWN	27	10.4	DOLOMITE: Thick-bedded to massive; occasionally argillaceous, occasional shale partings and bands; moderately hard; very finely crystalline to dense. Contains an Intraformational Conglomerate zone from 0.1 to 1.0-foot thick at or near the base and another 0.2 to 0.9-foot thick from 1.8 to 3.2 feet above the base. The Intraformational Conglomerate consists of small gray dolomite fragments in a lighter gray dolomite matrix. Gray to dark gray.
			26	4.5 to 6.4	DOLOMITE: Thin to medium-bedded; shaly and argillaceous at top and bottom with a basal sandy textured shale, numerous calcite veinlets in darker gray dolomite at top and bottom; moderately hard to hard; finely crystalline to dense; dark gray at top and bottom, bluish-gray in middle.
			25	8.9 to 10.2	DOLOMITE: Thin to medium-bedded; numerous stylolitic shale and calcite partings, shale and dolomitic shale partings, bands and beds with shale band at base; moderately hard to hard; very finely crystalline to dense; Intraformational Conglomerate at base. Unit is pitted and vuggy; medium bluish-gray.
			24	3.4 to 4.6	DOLOMITE: Thin-bedded top and bottom, massive in middle; frequent hairline stylolitic shale partings; moderately hard; dense in upper 0.3-foot and 0.5 to 0.6-foot; finely crystalline in middle; fossiliferous (?); medium gray.

Table 1 (cont'd)
Stratigraphic Units in Bedrock

SYSTEM	STAGE	GROUP	UNIT	THICK-NESS	DESCRIPTION
ORDOVICIAN		BEEKMANTOWN	23	1.0+	SHALE: Laminated, dolomitic; moderately hard; dark gray.
			22	5.1 to 5.6	DOLOMITE: Thick-bedded to massive; argillaceous, several shaly bands throughout; moderately hard; dense; light gray at top, bluish-gray middle and brownish-gray at base.
			21	0.9	SHALE and DOLOMITE: Thin-bedded; shale is dolomitic and dolomite is argillaceous, interbedded; slightly sandy texture at base; moderately hard; dense; dark gray.
			20	3.6 to 4.1	DOLOMITE: Thin to thick-bedded; moderately hard; dense; bluish-gray upper, medium gray in lower. Shale 0.1 to 0.3-foot at base, and 0.3-foot thick approximately 0.7-foot below top. May or may not contain 2 zones of Intraformational Conglomerate; one directly above the upper shale (0.2-foot thick) and one 1.5 feet below top of unit (0.7-foot thick) (Not present in all cores). Calcite veinlets occur 1.1 feet below top.
			19	2.4 to 3.0	DOLOMITE: Thin-bedded; argillaceous, several stylolitic shale partings, basal shale is (0.3-foot thick) platy to laminated, slightly carbonaceous; moderately hard; black. Dolomite contains numerous high angle veinlets of calcite throughout; moderately hard; dense; occasional vugs filled with calcite with some solutioned out; dark gray to black.
			18	2.0 to 3.6	DOLOMITE: Thin to thick-bedded; slightly argillaceous. Basal platy black shale (0.1 to 0.3-foot thick) and bands of shale interbedded with dolomite approximately 0.8-foot and 1.4 feet from base; stylolitic shale partings in upper 0.3-foot; moderately hard; very finely crystalline to dense; occasional pits and vugs in upper 0.7-foot; bluish-gray.
			17	1.1 to 2.1	DOLOMITE: Thin to medium-bedded; very argillaceous, shaly appearance with several black shale partings and bands; moderately hard; dense; very dark gray.
			16	8.5	DOLOMITE: Medium to thick-bedded; slightly argillaceous, shale bands and beds throughout; gypsum bands, beds and masses with occasional partings in lower part; moderately hard; very finely crystalline to dense; occasional pits and vugs where gypsum has been removed; bluish-gray to brownish-gray.

Table 1 (cont'd)
Stratigraphic Units in Bedrock

SYSTEM	STAGE	GROUP	UNIT	THICK-NESS	DESCRIPTION
ORDOVICIAN		BEEKMANTOWN	15	1.4 to 3.8	GYPSUM: Thin to medium-bedded; laminated and interbedded satinspar and gypsum in upper part, irregular laminated gypsum in lower part; soft to moderately hard; dense to crystalline; mottled various shades of light and dark gray.
			14	1.9 to 3.8	DOLOMITE: Thin-bedded; argillaceous with gypsum partings and irregular partings at base; a 0.1 to 0.3-foot thick dolomitic shale with partings mark top of unit; moderately hard to hard; dense; medium gray to gray.
			13	24.4	DOLOMITE: Thin to medium-bedded; numerous bands and beds of darker gray shaly to argillaceous dolomite; dark gray to black shale bands approximately 2.4 feet below top, and a black platy carbonaceous shale approximately 2.0 feet above base of unit; moderately hard; dense; pitted and vuggy near basal foot; brownish-gray to bluish-gray.
			12	2.1 to 2.7	DOLOMITE: Thin to medium-bedded; shale partings and stylolitic shale partings throughout. Black platy dolomitic shale (0.2-foot thick) at top, and a basal sandy dolomite (0.04-foot thick). Base of unit is marked by a black fissile shale with gypsum partings. Moderately hard; dense; brown to brownish-gray.
			11	7.1 to 10.7	DOLOMITE: Medium-bedded upper, thick-bedded lower; shale bands in upper 1.1 to 1.5 feet with stylolitic shale partings and bands in upper part, gypsum masses in middle, lower part is nearly a mass of laminated gypsum (3.0 feet); moderately hard; (gypsum is soft to moderately hard) dense; medium gray.
			10	5.6 to 5.9	DOLOMITE: Thin to thick-bedded; argillaceous with shale and gypsum partings and occasional gypsum nodules; moderately hard; dense; medium gray upper, light gray middle and brownish-gray lower.
			9	2.9	DOLOMITE: Thin-bedded; gypsum partings and shale bands, shale band approximately 0.6-foot below top (0.1-foot thick); moderately hard; dense; bluish-gray.
			8	1.7	DOLOMITE: Thin to thick-bedded; very shaly with gypsum partings; moderately hard; occasional pits filled with gypsum; dark gray to black.

Table 1 (cont'd)
Stratigraphic Units in Bedrock

SYSTEM	STAGE	GROUP	UNIT	THICK-NESS	DESCRIPTION
ORDOVICIAN		BEEKMANTOWN	7	1.8	DOLOMITE: Thin-bedded-flaggy appearance with numerous gypsum-satinspar partings; moderately hard; very finely crystalline to dense; brownish-gray to bluish-gray.
			6	2.1 to 2.6	DOLOMITE: Thin-bedded; abundant gypsum partings and stylolitic shale partings. A 0.1-foot thick dolomitic shale at top; moderately hard; very finely crystalline to dense; lower part highly fractured - fractures filled with gypsum; light gray to light bluish-gray.
			5	6.3	GYPSUM and DOLOMITE: Gypsum in upper 0.6 to 0.9-foot (0.4-foot thick), fractured gypsum and shaly dolomite at base; laminated to thin-bedded; gypsum partings throughout; moderately hard; dense; white at top, medium dark gray lower part.
			4	3.1 to 5.0	DOLOMITE: Thin to thick-bedded; argillaceous in top 1.0-foot with sandy textured dolomitic shale band at top (gray to dark gray), several dolomitic shale partings and bands throughout; dense; moderately hard; medium to dark gray.
			3	2.5 to 3.6	SHALE and DOLOMITE: Laminated to thin-bedded; shale interlaminated with gypsum in upper 1.0 to 1.5 feet. Dolomite in middle 0.7-foot and shaly dolomite in basal 0.8-foot. Dolomite and shaly dolomite are dense; shale is soft; dolomite and shaly dolomite are moderately hard; light gray to black.
			2	17.2	DOLOMITE-LIMESTONE: Thin to thick-bedded; shale and stylolitic shale partings throughout, particularly near basal contact, secondary gypsum approximately 1.6 feet and 3.0 feet from top, occasional gypsum partings; moderately hard; very finely crystalline to dense; medium to light gray.
			1	9.3	DOLOMITE: Thin to thick-bedded; argillaceous, numerous shale and argillaceous dolomite partings and bands throughout, gypsum partings and fracture filling common; moderately hard; dense; bluish-gray.
			0	1.2	SHALE: Laminated; dolomitic; moderately hard; dark gray to black.

Notes for Table 1

The description of the soils and bedrock on Table 1 is based on the following criteria:

SOILS

1. Classification - all soils are classified using the Unified Soil Classification System.

2. Consistency - For drive sample borings the following was used to determine relative density or consistency. Consistency for gravels is not used.

Basic Soil Type	Density or Consistency	Range of Standard Penetration Resistance (1)
Cohesionless	Very loose	less than 4 per foot
	Loose	4 to 10
	Medium dense	10 to 30
	Dense	30 to 50
	Very dense	Greater than 50
Cohesive	Very soft	Less than 2 per foot
	Soft	2 to 4
	Medium stiff	4 to 8
	Stiff	8 to 15
	Very stiff	15 to 30
	Hard	Greater than 30

(1) Number of blows from 140-lb. weight falling 30 inches to drive 2-inch OD, 1-3/8-inch ID, sampler

For undisturbed sample borings a pocket pentrometer or torvane was used to determine consistency and the following was used as a guide:

Unconfined Compressive Strength (Tons/Sq Ft)	Consistency
Less than .25	Very soft
.25 - .5	Soft
.5 - 1.0	Medium
1.0 - 2.0	Stiff
2.0 - 4.0	Very stiff
Greater than 4.0	Hard

3. Moisture Content - Moisture content of soil has been described in the following terms:

Dry. No discernible moisture present.

Damp. Enough moisture present to darken the appearance but no moisture on material adheres to the hand.

Moist. Will moisten the hand.

Wet. Visible water present; plastic materials will leave sticky residue in hand when remolded.

Saturated. 100 percent of all the void space is filled with water.

4. Color - Color was described at the time of drilling.

BEDROCK

1. Bedrock classification was based on the rock types described in the foundation reports for the two existing locks. The rock units described in this report are based on the descriptions shown in the foundation reports (see references 13 and 14). In addition to those descriptions the following criteria was used to describe the bedrock. All descriptions are based on a visual examination at the time of drilling.

2. Bedding - Has been described as massive, thin to medium bedded, fissile, cross-bedded, foliated, platy, fragmental, etc., as indicated below:

(a)	Parting	less than 0.02 foot
(b)	Band	0.02 foot to 0.2 foot
(c)	Thin Bed	0.2 foot to 0.5 foot
(d)	Medium Bed	0.5 foot to 1.0 foot
(e)	Thick Bed	1.0 foot to 2.0 feet
(f)	Massive	Over 2.0 feet

Parting and Band refer to single stratum. The term "massive" may be applied to describe a single bed.

3. Lithologic Characteristics - clayey, shaly, calcareous (limy) siliceous, sandy, silty, plastic seams.

4. Hardness.

very soft or plastic - can be indented easily with thumb
soft - can be scratched with fingernail
moderately hard - can be scratched easily with knife; cannot be scratched with fingernail
hard - difficult to scratch with knife
very hard - cannot be scratched with knife

5. Crystallinity or texture.

dense - crystals are so small that they cannot be distinguished with the naked eye.
very finely crystalline - crystals barely discernible with the naked eye.
finely crystalline - crystals are small but easily discernible with naked eye.
crystalline - crystals are medium size - up to 1/8 inch in diameter.
very coarsely crystalline - crystals larger than 1/4 inch in diameter.

6. Pit - Vug - Cavity - In order to more closely define voids found in bed rock, the following terms have been used:

Porous. Smaller than pinhead. Usually not discernible to the naked eye. Their presence is indicated by the degree of absorbency of the core.

Pitted. Pinhead size to 1/4-inch. If they are numerous enough that only thin walls separate the individual pits, the core may be described as honeycombed.

Vug. 1/4-inch to the diameter of the core. The upper limit will vary with the size of core.

Cavity. Larger than the diameter of the core.

7. Structure.

Bedding: flat, gently dipping, steeply dipping.

Fractures: scattered, closely spaced, open, cemented, or tight.

Brecciated (sheared & fragmented).

Joints.

Faulted.

Slickensides.

8. Degree of Weathering. Unweathered, slightly weather; badly weathered.

9. Solution and Void Conditions. Solid, contains no voids; vuggy (pitted); vesicular; porous; cavities; cavernous.

10. Swelling Properties. Nonswelling; swelling

11. Slaking Properties. Nonslaking; slakes slowly on exposure; slakes readily on exposure.

12. Color of Unit.

Table 2

EISENHOWER "TWIN" LOCK

Summary of Boring Data

Boring No.	Location (Canal Stationing)	Elevation (feet) IGLD - 1955			Linear Feet of Drilling	
		Surface	Top of Bedrock	Bottom of Boring	Soil	Rock
UDC-681201	Sta. 384+00 Rg. 7+40 Rt.	201.7	126.1	93.6	75.6	32.5
UDC-681202	Sta. 377+00 Rg. 4+60 Rt.	200.9	139.9	101.6	61.0	38.3
C-681203	Sta. 363+80 Rg. 3+15 Rt.	243.0	144.4	37.9	98.6	106.5
C-681204	Sta. 358+00 Rg. 2+25 Rt.	250.0	141.5	39.0	108.5	102.5
C-681205	Sta. 370+00 Rg. 2+48.6 Rt.	209.6	132.5	30.6	77.1	101.9
C-681206	Sta. 361+10 Rg. 34 Lt.	250.1	-----	172.6	77.5	-----
C-681207	Sta. 363+80 Rg. 6+90 Rt.	233.4	135.2	31.7	98.2	103.5
AC-681208	Sta. 384+00 Rg. 7+15 Rt.	201.1	126.6	25.6	74.5	101.0
AC-681209	Sta. 370+00 Rg. 9+95 Rt.	225.3	132.1	29.1	93.2	103.0
C-681210	Sta. 358+14 Rg. 1+15 Rt.	249.0	139.0	36.9	110.0	102.1
C-681211	Sta. 363+80 Rg. 65 Rt.	248.3	141.1	36.3	107.2	104.8
C-681212	Sta 360+47 Rg. 1+49 Rt.	247.6	143.4	139.1	104.2	4.3

Table 3
SNELL "TWIN" LOCK
Summary of Boring Data

Boring No.	Location (Canal Stationing)	Elevation (feet) IGLD - 1955			Linear Feet of Drilling	
		Surface	Top of Bedrock	Bottom of Boring	Soil	Rock
C-701301	Sta. 545+42 Rg. 5+35 Rt.	206.5	132.0	33.7	74.5	98.3
C-701302	Sta. 545+62 Rg. 3+55 Rt.	205.9	130.9	29.7	75.0	101.2
C-701303	Sta. 545+72 Rg. 2+45 Rt.	205.1	129.1	28.2	76.0	100.9
C-701304	Sta. 557+72 Rg. 6+35 Rt.	165.2	99.2	-2.8	66.0	102.0
C-701305	Sta. 557+61 Rg. 2+45 Rt.	159.7	103.7	6.7	56.0	97.0
UC-701306	Sta. 557+72 Rg. 4+10 Rt.	156.2	103.5	3.2	52.7	100.3
C-701307	Sta. 551+70 Rg. 2+45 Rt.	167.4	120.1	19.8	47.3	100.3
C-701308	Sta. 550+82 Rg. 4+05 Rt.	174.5	121.4	66.7	53.1	54.7
UD-701308A	Sta. 550+87 Rg. 4+05 Rt.	174.5	-----	155.5	19.0	-----
C-701309	Sta 548+12 Rg. 4+20 Lt.	182.1	91.0	36.5	91.1	54.5
C-701310	Sta. 551+72 Rg. 7+70 Rt.	169.5	126.6	80.4	42.9	46.2

Table 4

1940-41 Survey: Seismic Velocities of Materials

Material	Average Seismic Velocities (fps)
1. Very loose material	1000 - 2000
2. Relatively soft material (silt or clay) or loose till	4500 - 5000
3. Compact glacial till	>5000
4. Bedrock	16,400

Table 5

1970 Survey: Seismic Velocities and Electrical Resistivities of Materials

	Average Seismic Velocities (fps)		Average Electrical Resistivity (ohm-ft)	
Material	Snell	Eisenhower	Snell	Eisenhower
1. Soil and backfill	1700-3300	1200-3800	220-4300	97-850
2. Till	6700	7100	325	436
3. Marine clay	5100	4900	820	121
4. Bedrock	16,500	17,200	2500-∞	1323-∞

Table 6

TEST DATA SUMMARY

PROJECT SLS - EISENHOWER "TWIN" LOCK ALTERNATIVE

SHEET 1 OF 2

Boring No.	Samp. No.	Depth of Sample	Laboratory Classification	Mechanical Analysis				Atterberg Limits		Specific Gravity G	Nat Water Cont %	Natural Dry Density Lbs/Cu Ft	Compaction Data		Shear Data												Permeability		Consolidation Data				Remarks
				Gravel %	Sand %	Fines %	D_{10}	LL	PL				Opt Water %	Maximum Dry Density Lbs/Cu Ft	Initial e	Dry Density Lbs/Cu Ft	w_i %	w_f %	S_i %	Type Test	Specimen Size Inches	Test	σ_m T/Sq Ft	σ_1 T/Sq Ft	c T/Sq Ft	φ Degrees	e	K Ft/Min	P_o T/Sq Ft	P_c T/Sq Ft	C_c	t_{50}	
UDC-681201 El. 201.7 Grd Surface																																	
	1	9.3-11.3	Clay (CL-CH)					48	21	2.75					1.036	84.3	37.2		98.8	T	1.41 x 2.9	Q	0.5	1.38	0.74								
	2	11.8-14.2	Clay (CH)					59	24	2.77					1.417	71.5	50.8		99.3		1.41 x 2.91			1.64	0.57								
	3	16.8-19.2	Clay (CL)					36	17	2.75					1.185	78.5	43.1		100.0		1.34 x 2.94			1.49	0.495								
	4	21.5-23.9	Clay (CL-CH)					48	24	2.76					1.792	61.7	65.1		100.3		1.40 x 2.92			1.32	0.41								
	5	26.5-28.9	Clay (CH)					57	26	2.76					1.907	59.2	68.4		99.0		1.36 x 2.94			1.31	0.405								
	6	31.5-33.9	Clay (CH)					56	25	2.78					1.902	59.8	67.6		98.3		1.35 x 2.95			1.49	0.495								
	7	36.5-38.9	Clay (CH)					64	27	2.77					1.965	58.3	70.0		98.7		1.40 x 2.92			1.32	0.41								
	8	41.5-43.7	Clay (CL)					46	25	2.76					1.831	60.8	65.4		98.6		1.37 x 2.95			1.51	0.505								
	9	46.5-48.9	Clay (CL)					47	26	2.76					1.893	59.5	68.4		99.7		1.38 x 2.94			1.45	0.475								
	10	51.5-53.5	Clay (CL)					46	21	2.77					1.850	60.6	66.4		99.4		1.38 x 2.94			1.47	0.485								
	11	56.5-58.9	Clay (CL)					47	23	2.78					1.7000	64.2	59.3		97.0		1.37 x 2.94			1.66	0.58								
	12	61.5-63.9	Clay (CH)					55	24	2.80					1.642	66.1	57.4		97.9		1.36 x 2.95			2.43	0.965								
	13	66.5-68.9	Clay (CL)					47	22	2.79					1.375	73.3	49.2		99.8		1.39 x 2.94			1.53	0.515								
	14	71.5-73.9	Clay (CL)					33	18	2.76					0.974	87.2	34.6		98.0	T	1.40 x 2.94	Q	0.5	1.48	0.49								
UDC-681202 El. 200.9 Grd. Surface																																	
	1	12.0-14.4	Clay (CL)					45	19	2.77					1.253	76.7	44.8		99.1	T	1.40 x 2.94	Q	0.5	1.31	0.405								
	2	17.0-19.3	Clay (CH-CL)					52	23	2.77					1.656	65.1	59.2		99.0		1.39 x 2.94			1.69	0.595								
	3	22.0-22.9	Sandy Clay (CH)					53	25	2.79					1.820	61.7	64.8		99.4		1.39 x 2.94			1.40	0.45								
	4	27.0-29.5	Sandy Clay (CH)					54	25	2.77					1.786	62.0	64.1		99.4		1.38 x 2.94			1.31	0.405								
	5	32.0-34.4	Clay (CH)					55	24	2.77					1.651	65.2	59.3		99.5		1.39 x 2.94			1.45	0.475								
	6	37.0-39.4	Sandy Clay (CH)					56	24	2.79					1.739	63.6	61.7		99.0		1.38 x 2.94			1.21	0.355								
	7	42.0-44.4	Clay (CH)					55	22	2.78					1.477	70.0	52.8		99.4		1.39 x 2.94			1.24	0.37								
	8	47.0-49.0	Sandy Clay (CH)					57	25	2.79					1.282	76.3	45.7		99.4		1.39 x 2.94			1.58	0.54								
	9	52.0-54.4	Sandy Clay (CH-CL)					50	23	2.77					1.290	75.5	46.3		99.4	T	1.39 x 2.94	Q	0.5	1.53	0.515								

ENG FORM 2086 EDITION OF 1 MAR 68 IS OBSOLETE
1 JAN 72

T - TRIAXIAL COMPRESSION
UC - UNCONFINED COMPRESSION
DS - DIRECT SHEAR
Q - UNCONSOLIDATED UNDRAINED
S - CONSOLIDATED DRAINED
R - CONSOLIDATED UNDRAINED

Table 6a

Table 6

TEST DATA SUMMARY

PROJECT SLS - EISENHOWER "TWIN" LOCK ALTERNATIVE

SHEET 2 OF 2

BORING NO.	SAM NO.	DEPTH OF SAMPLE	LABORATORY CLASSIFICATION	MECHANICAL ANALYSIS: GRAVEL %	SAND %	FINES %	D_{10}	ATTERBERG LIMITS: LL	PL	SPECIFIC GRAVITY G	NAT WATER CONT %	NATURAL DRY DENSITY LB/CU FT	COMPACTION DATA: OPT WATER %	MAXIMUM DRY DENSITY LB/CU FT	SHEAR DATA: INITIAL e	DRY DENSITY LB/CU FT	w_1 %	w_f %	S_1 %	TYPE TEST	SPECIMEN SIZE INCHES	TEST	σ_m T/SQ FT	σ_1 T/SQ FT	c T/SQ FT	φ DEGREES	PERMEABILITY: e	K FT/MIN	CONSOLIDATION DATA: P_o T/SQ FT	P_c T/SQ FT	C_c	t_{90}	REMARKS
C-69120K		El. 50.1 Grd. Surf.																															
	2	1.7-2.9	Si. Sand, Gr (SM)	19	44	37		16	14	2.73	6.3				0.201	141.8	6.3		85.5	T	3.59 x 8.0	Q	2.0	14.8	1.89	35°10'							
(1)	6	5.2-6.3	Si. Sand, Gr (SM)	23	37	40		15	13	2.73(E)	5.8				0.240	137.4	6.9		78.5	T	3.87 x 8.2	Q	0.5	9.3									
	9	6.7-7.8	Si. Sand, Gr. (SM)	29.5	33.5	37		Visual		2.75	6.9				0.175	146.1	5.8		91.4	T	3.79 x 10.2	Q	1.0	5.05									
	11	8.6-10.0	Si. Sand, Gr. (SM)	22	34	44		Visual		2.74(E)	7.2				0.199	143.3	7.2		98.6	T	3.83 x 12.25	Q	1.0	5.30	1.37	34°40'							
	12	10.0-11.3	Si. Gravel, Sa. (GM-SC)	36	32	30		17	13	2.73	6.6				0.181	144.2	6.6		100	T	3.87 x 12.15	Q	4.0	11.32									
(2)	14	12.2-13.3	Si. Sand, Gr. (SM)	32	33	35		16	13	2.74(E)	3.5				0.147	149.1	3.5		66.1	T	3.82 x 10.51	Q	2.0	12.54									
	16	14.0-15.2	Si. Sand, Gr. (SM)	22	41	37		Visual		2.72	5.4				0.185	143.2	5.4		79.7	T	3.88 x 11.12	Q	0.5	7.12									
	17	15.2-15.9	Si. Gravel, Sa. (GM-SC)	44	25	31		15	11	2.73	4.1				0.133	150.4	4.1		84.4	T	3.72 x 9.44	Q	1.0	10.71	1.22	35°50'							
	21	18.7-19.9	Si. Sand, Gr. (SM-SC)	23	34	43		Visual			7.5																						
(3)	22	19.9-21.1	Si. Gravel, Sa. (GM-SC)	34	32	34		15	10	2.73	4.2				0.153	147.8	4.2		75.5	T	3.71 x 10.29	Q	2.0	12.53									
	56	59.3-60.2	Si. Sand, Gr (SM)	22	41	37		Visual		2.73(E)	5.6				0.175	145.0	5.6		87.3	T	3.88 x 11.5	Q	0.5	6.74									
	25	22.3-24.0	Si. Sand, Gr. (SM-SC)	20	38	42		15	11	2.72(E)	4.4				0.150	147.6	4.4		79.9	T	3.68 x 10.47	Q	0.5	8.61	1.40	41°							
	26	24.0-26.1	Si. Sand, Gr (SM-SC)	18	42	40		15	10	2.72	4.9				0.162	146.1	4.9		82.5	T	3.70 x 9.80	Q	2.0	15.78									
(4)	28	27.6-29.3	Si. Sand, Gr. (SM-SC)	35	37	28		Visual			4.9																						
	29	29.3-30.0	Si. Sand, Gr. (SM-SC)	23	40	37		Visual		2.72	4.3				0.160	146.3	4.3		73.1	T	3.75 x 10.31	Q	1.0	11.24									
	32	32.5-34.0	Si. Sand, Gr (SM-SC)	21	37	42		Visual		2.72	7.1				0.206	140.7	7.1		93.8	T	3.70 x 9.76	Q	2.0	9.94	0.74	42°20'							
	33	34.0-35.3	Si. Sand (SM-SC)	12	45	43		15	10	2.75	5.3				0.219	140.8	5.3		67.0	T	3.74 x 12.13	Q	1.0	8.45									
(5)	34	35.3-36.9	Si. Sand, Gr (SM-SC)	32	36	32		16	11	2.74(E)	5.0				0.185	144.3	5.0		74.1	T	3.79 x 11.31	Q	0.5	7.2									
	38	39.4-40.4	Si. Sand (SM-SC)	13	45	42		Visual		2.74(E)	5.5				0.216	140.5	5.5		69.2	T	3.79 x 12.25	Q	4.0	23.76									
	40	40.8-41.9	Si. Sand & Gravel (GM)	30	29	41		Visual			4.3				0.163	147.5	4.3		72.5	T	3.83 x 11.50	Q	0.5	6.29	0.55	47°20'							
	42	42.3-43.5	Si. Sand, Gr. (SM-SC)	32	38	33		15	11		4.6				0.164	145.3	4.6		76.4	T	3.66 x 7.00	Q	1.0	10.56									
(6)	44	44.9-46.0	Si. Sand, Gr. (SM)	20	47	33		13	12		4.3				0.179	144.4	4.3		65.4	T	3.52 x 8.52	Q	2.0	16.13									
	45	49.0-50.3	Si. Gravel, Sa. (GM)	42	33	25		Visual			—																						
	50	53.6-54.7	Si. Sand, Gr. (SM-SC)	26	37	37		14	10	2.76	4.4				0.168	145.9	4.4		71.2	T	3.47 x 10.50	Q	2.0	14.05	0.25	42°16'							
	51	54.7-55.6	Si. Sand & Gravel (GM-SC)	35	34	31		Visual		2.73(E)	6.7				0.239	137.4	6.7		76.0	T	3.57 x 9.41	Q	1.0	5.56									
(7)	53	55.9-56.9	Cl. Gravel, Sa. (GC)	52	22	26		19	11	2.73(E)	3.2				0.124	153.3	3.2		72.3	T	3.70 x 11.04	Q	0.5	11.31									
	54	56.9-58.0	Si. Sand, Gr. (SM-SC)	16	41	43		14	10	2.73	6.3				0.193	142.7	6.3		89.0	T	3.71 x 11.30	Q	4.0	20.51									
	55	58.0-59.3	Cl. Gravel, Sa. (GC)	44	33	23		21	12	2.75	4.8				0.177	145.8	4.8		74.4	T	3.61 x 8.30	Q	2.0	15.55	0.80	45°							
	59	61.6-63.0	Si. Sand, Gr. (SM)	14	52	34		Visual		2.71	9.3				0.302	129.9	9.3		89.6	T	3.77 x 8.99	Q	0.5	7.77									
(8)	62	64.5-65.0	Si. Gravel, Sa. (GM)	40	27	33		14	11	2.71(E)	2.3				0.122	152.5	2.9		52.3	T	3.72 x 10.43	Q	1.0	13.99									
	64	66.2-67.5	Si. Sand & Gravel (SM)	31	34	35		Visual		2.74	4.7				0.186	144.2	4.7		69.6	T	3.65 x 8.23	Q	4.0	28.67									

ENG FORM 2089 1 JAN 73 EDITION OF 1 MAR 55 IS OBSOLETE

NOTE: Circled numbers ((8)) indicate specimens of a given triaxial compression test series.

T - TRIAXIAL COMPRESSION
UC - UNCONFINED COMPRESSION
DS - DIRECT SHEAR
Q - UNCONSOLIDATED UNDRAINED
S - CONSOLIDATED DRAINED
R - CONSOLIDATED UNDRAINED

Table 6b

Table 7

TEST DATA SUMMARY

PROJECT SLS - SNELL "TWIN" LOCK ALTERNATIVE

SHEET 1 OF 1

Boring No.	Samp. No.	Depth of Sample	Laboratory Classification	Mechanical Analysis: Gravel %	Sand %	Fines %	D_{10}	Atterberg Limits: LL	PL	Specific Gravity G	Nat Water Cont %	Natural Dry Density Lbs/Cu Ft	Compaction Data: Opt Water %	Maximum Dry Density Lbs/Cu Ft	Shear Data: Initial e	Dry Density Lbs/Cu Ft	w_i %	w_f %	S_i %	Type Test	Specimen Size Inches	Test	σ_m T/Sq Ft	q_1 T/Sq Ft	c T/Sq Ft	φ Degrees	Permeability: e	K Ft/Min.	Consolidation Data: P_o T/Sq Ft	P_c T/Sq Ft	C_c	t_{90}	Remarks
UC-7013G6 El 156.2 Grd. Surface																																	
	1	6.0-8.5	Clay (CH)					59	26	2.77	62.0	63.7			1.734	63.2	62.7		100.1	T	1.40×2.94	Q	0.5	1.78	0.89								
	2	8.5-10.0	Clay (CH)					59	26	2.77					1.733	63.3	62.7		100.2		1.39×2.95			1.39	0.695								
	3	10.0-12.5	Clay (CH)					56	25	2.77	55.5	68.1			1.504	69.0	54.7		100.8		1.38×2.94			1.90	0.95								
	4	12.5-15.0	Clay (CH)					56	26	2.76					1.694	63.9	61.4		100.1		1.38×2.95			1.76	0.88								
	5	15.0-17.4	Clay (CH)					54	26	2.76	60.5	64.5			1.635	65.4	59.6		100.6		1.37×2.94			1.63	0.815								
	6	17.5-19.9	Clay (CH)					54	25	2.76	59.7	65.3			1.675	64.4	6[illegible].0		100.5		1.36×2.94			1.69	0.845								
	7	20.0-22.4	Clay (CH-CL)					[illegible]	[illegible]	2.76					1.605	66.1	58.6		100.8		1.38×2.94			1.24	0.62								
	8	22.5-24.9	Clay (CH)					52	25	2.76					1.648	65.0	60.0		100.5		1.38×2.95			1.21	0.606								
	9	25.0-27.4	Clay (CH-CL)					50	24	2.77	60.[illegible]	64.8			1.672	64.7	60.4		100.0		1.37×2.95			1.38	0.69								
	10	27.5-29.9	Clay (CH)					54	25	2.76					1.728	63.1	62.9		100.4		1.38×2.95			1.46	0.73								
	11	30.0-32.4	Clay (CH)					57	26	2.77	64.4	[illegible]			1.793	61.9	64.9		100.3		1.37×2.95			1.59	0.795								
	12	33.5-34.8	Clay (CH)					53	25	2.78					1.759	62.9	63.4		100.2		1.38×2.95			1.56	0.78								
	13	35.0-37.4	Clay (CH)					52	23	2.78	64.3	62.2			1.759	62.9	63.4		100.2		1.38×2.94			1.43	0.715								
	14	37.5-39.9	Clay (CH)					58	26	2.80					1.687	65.0	60.3		100.0		1.38×2.94			1.86	0.93								
	15	40.0-42.4	Clay (CH)					55	24	2.80	57.[illegible]	67.2			1.604	67.1	57.5		100.4		1.39×2.93			1.15	0.575								
	16	45.0-46.[illegible]	Clay (CL)					40	19	2.77					1.201	78.5	43.4		100.0	T	1.38×2.95	Q	0.5	1.11	0.555								
UC-7013[illegible] El 156.2 Grd Surface																																	
	11	30.0-32.4	Clay (CH)					57	26	2.77					1.757	[illegible].7	63.4	59.4	100.0	T	1.40×2.93	S	0.5	2.04									
	13	35.0-37.4	Clay (CH)					52	23	2.78					1.743	62.9	63.3	59.5	100.0	T	1.39×2.94	S	0.5	1.81									
	15	40.0-42.4	Clay (CH)					55	24	2.80					1.585	67.4	56.9	54.5	100.0	T	1.39×2.93	S	0.5	1.90									
UD-7013CBA El.174.[illegible] Grd. Surface																																	
	1	6.6-8.4	Clay (CH)					58	23	2.74	33.4	89.3			0.915	89.5	32.4		97.0	T	1.39×2.94	Q	0.5	2.72	1.36								
	2	12.0-14.9	Clay (CH)					60	22	2.78	47.5	74.5			1.555	74.3	47.3		97.5	T	1.36×2.96	Q	0.5	1.89	0.945								

ENG FORM 2089 1 JAN 73 EDITION OF 1 MAR 69 IS OBSOLETE.

T - TRIAXIAL COMPRESSION
UC - UNCONFINED COMPRESSION
DS - DIRECT SHEAR
Q - UNCONSOLIDATE UNDRAINED
S - CONSOLIDATED DRAINED
R - CONSOLIDATED UNDRAINED

Table 7

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Table 8
SUMMARY OF ROCK CORE TESTS

ORD Laboratory
Cincinnati, Ohio

Project Twin Lock Study, Eisenhower Lock, St. Lawrence Seaway Date July 1970

Sheet 1 of 2

Identification Data				Strength Tests Data (in pounds per square inch)														Physical Data			
				Compression			Direct Shear			Sliding Friction		Grout on Rock			Triaxial Comp.						
Boring No.	Sample No.	Elev.	Rock Type	Unit Load at Fail.	Mod. Elas psi 10^6	Tensile	Normal Unit Load	Direct Unit Load at fail.	Max. Slide Resist.	Norm. Stress	Sliding Resist.	Norm. Unit Load	Bond Strength	Max. Slide Resist.	σ_3	Max. $\sigma_1 - \sigma_3$	Ult. $\sigma_1 - \sigma_3$	Nat. Water %	Specific Gravity	Absorption	Unit Weight lb/ft3
C-68	1	136.75'-	Dolomite	16,160	2.11							50	89	79				1.0			173.6
1210		135.8'										100	329	315							
												150	281	246							
	2	129.9'-	Dolomite							50	19	(R/SmR)									
		129.2'								100	41	"									173.4
										150	66	"									
	3	120.3'-	Dolomite																		
		119.4'													0	11,370		0.5			175.3
															2500	43,790		0.5			174.0
	4	115.15'-	Dolomite	13,090	2.54																
		114.4'																1.2			173.0
	5	113.95'-	Argillaceous																		
		112.8'	dolomite															0.8			169.4
	6	109.4'-	Argillaceous																		
		108.7'	dolomite															0.9			171.2
	7	106.8'-	Argillaceous									50	49	36	(G/SmR)						
		105.9'	dolomite									100	78	68	"						
												150	141	133	"						
	8	101.85'-	Dolomite,												1000	17,590		0.5			167.8
		100.6'	argillaceous												2000	55,530		0.3			174.6
															3000	25,340		0.4			172.0
	10	97.0'	Argillaceous																		
		96.4'	dolomite															0.3			174.0

ShR = Sheared Rock Surface G/roR = Grout on rough Rock Surface, Cured 7 days.
R/smR = Smooth Rock Surface G/SmR = Grout on Smooth Rock Surface, Cured 7 days.

ORD Form
1 April 75 975

ED-FL

Table 8a

Table 8
SUMMARY OF ROCK CORE TESTS

ORD Laboratory
Cincinnati, Ohio

Project *Twin Lock Study Eisenhower Lock, St. Lawrence Seaway* Date *July 1970* Sheet *2* of *2*

Identification Data				Strength Tests Data (In pounds per square inch)														Physical Data			
				Compression		Tensile	Direct Shear			Sliding Friction		Grout on Rock			Triaxial Comp.						
Boring No.	Sample No.	Elev.	Rock Type	Unit Load at Fail.	Mod. Elas E 10^6		Normal Unit Load	Direct Unit Load at fail.	Max. Slide Resist.	Norm. Stress	Sliding Resist.	Norm. Unit Load	Bond Strength	Max. Slide Resist.	σ_3	Max. $\sigma_1 - \sigma_3$	Ult. $\sigma_1 - \sigma_3$	Nat. Water	Specific Gravity	Absorption	Unit Weight lb/ft3
C-68	12	84.96'-	Gypsum	1,820														0.4			143.0
1210		83.95'																			
C-68		138.15'-	Dolomite	32,670	5.76													0.3			174.8
1211	18	137.1'	Dolomite	3,640	0.92													0.3			174.7
	2	135.05'-	Dolomite	16,160	2.38					50	31	(R/SmR)						0.2			173.7
		133.85'								100	56	"									
										150	86	"									
	3	124.1'-	Dolomite												500	23,640		1.7			168.3
		122.9'													1500	33,420		1.5			168.3
															2500	40,830		1.6			168.5
	4	121.7'-	Argillaceous				50	211	211									1.2			169.6
		120.4'	dolomite				100	336	244												
							150	717	903												
	5	120.4'-	Dolomite	18,490	3.05													0.5			173.6
		119.25'																			
	6	114.5'-	Dolomite									50	241	60							
		113.7'										100	233	133							
												150	142	79							
	7	109.55'-	Argillaceous	12,550	2.50													0.3			172.8
		108.4'	dolomite																		
	10	92.9'-	Gypsum	2,225	0.73													6.4			132.0
		91.95'																			

ShR = Sheared Rock Surface G/roR = Grout on rough Rock Surface, Cured 7 days.
R/smR = Smooth Rock Surface G/SmR = Grout on Smooth Rock Surface, Cured 7 days.

ORD Form
1 April 75 975

ED-FL

Table 8b

Notes for Table 8

1. Concern has been expressed over the fact that the values for unit weight of rock specimens tested in direct shear, triaxial shear, and unconfined compression do not always equal the specific gravity of the specimen times 62.4 pounds/cubic foot.

2. A search of the files was made and all of the of the work and data sheets were examined. It was determined that all values were actual determinations and that the discrepancies could be attributed to the following:

a. Both the specific gravity and the unit weight values were determined under saturated/surface-dry conditions.

b. Both determinations are very sensitive to small changes in water content. Heterogeneous rocks are especially sensitive to changes in water content below 25 percent.

c. The water content of rocks will decrease by 25 percent in 10 minutes when exposed to air at 60-65 percent relative humidity and 20-22°C. (Broch, E., "The Influence of Water on Some Rock Properties," Norwegian Institute of Technology, 1974).

d. The relation, Specific Gravity X 62.4 lbs./cu. ft. = unit weight, holds true only for homogeneous materials. Rock, in particularly this rock, is heterogeneous and, therefore, if a different specimen was used for each of the two tests, the value would differ by at least 4 or 5 lbs./cu. ft. Even if the same specimen was used, the difference could be 1-2 lbs/cu. ft.

Table 9

SUMMARY OF ROCK CORE TESTS

ORD Laboratory
Cincinnati, Ohio

Project Twin Lock Study, Snell Lock, St. Lawrence Seaway

Date April 1971

Sheet 1 of 2

Identification Data: Boring No.	Sample No.	Elev.	Rock Type	Strength Tests Data (in pounds per square inch): Compression: Unit Load at Fail.	Compression: Mod. Elas $\times 10^6$	Tensile	Direct Shear: Normal Unit Load	Direct Shear: Direct Unit Load at fail.	Direct Shear: Max. Slide Resist.	Sliding Friction: Type Test	Sliding Friction: Angle	Grout on Rock: Norm. Unit Load	Grout on Rock: Bond Strength	Grout on Rock: Max. Slide Resist.	Triaxial Comp.: σ_3	Triaxial Comp.: Max. $\sigma_1 - \sigma_3$	Triaxial Comp.: Ult. $\sigma_1 - \sigma_3$	Physical Data: Nat. Water	Specific Gravity	Absorption	Unit Weight lb/ft3
C-70	1	119.2'-	Dolomite									50	—	44							
1302		116.6'										100	167	94				0.29	2.79		174.3
												150	137	125							
	2	113.9'-	Dolomite	10,628	1.5										1000	35,000					
		110.6'													2000	91,000		0.84	2.78		173.4
	3	104.7'-	Dolomite												1500	108,500		0.71	2.78		174.4
		103.4'													3000	98,340					
	3	103.4'-	Dolomite				50	318	210						700	79,080		0.88	2.88		174.9
		101.2'					100	721							1400	91,340					
							150	670	346												
	4	101.2'-	Dolomite	14,875	3.4										400	65,800		1.07	2.82		176.7
		98.2													800	104,900					
	5	98.2'-	Argillaceous												1400	90,000		0.25	2.84		174.6
		95.2'	dolomite												2800	146,600					
	6	95.2'-	Dolomite	16,351	3.4										500	76,400		0.66	2.79		174.9
		91.8'													1000	85,800					
	8	88.25'-	Dolomite												[illegible]	[illegible]		1.38	2.78		174.4
		85.1'													2500	117,800					
C-70	2	110.25'-	Highly argilla-	6341	0.6		50	123	105									1.16	2.85		178.2
1303		107.1	ceous dolomite				100	220	180												
							150	472	437												
	4	105.3'-	Dolomite																		
		102.25'																			

ShR = Sheared Rock Surface G/roR = Grout on rough Rock Surface, Cured 7 days.
R/smR = Smooth Rock Surface G/SmR = Grout on Smooth Rock Surface, Cured 7 days.

Table 9

SUMMARY OF ROCK CORE TESTS

ORD Laboratory
Cincinnati, Ohio

Project Twin Lock Study, Snell Lock, St. Lawrence Seaway   Date April 1971   Sheet 2 of 2

Identification Data				Strength Tests Data (in pounds per square inch)														Physical Data			
				Compression			Direct Shear			Sliding Friction		Grout on Rock			Triaxial Comp.						
Boring No.	Sample No.	Elev.	Rock Type	Unit Load at Fail.	Mod. Elas psi 10^6	Tensile	Normal Unit Load	Direct Unit Load at fail.	Max. Slide Resist.	Type Test	Angle	Norm. Unit Load	Bond Strength	Max. Slide Resist.	σ_3	Max. $\sigma_1 - \sigma_3$	Ult. $\sigma_1 - \sigma_3$	Nat. Water	Specific Gravity	Absorption	Unit Weight lb/ft3
C-70	5	102.25'-	Dolomite				50	1532	No			50	505	67							
1303		98.8'					100	1300	Sliding			100	Lost	119							
							150	712				150	Bond	158							
	6	98.8'-	Dolomite																		
		95.6'																			
	8	92.2'-	Argillaceous	16,900	3.6										750	83,100		0.47	2.83		175.9
		89.3'	dolomite												1500	123,600					
UC-70	4	97.4'-	Dolomite									50	29	22							
1306		94.55'										100	57	46							
												150	89	67							
	6	93.3'-	Dolomite				50														
		90.3'					100	1315	1140												
							150	1562	1370												
	7	90.3'-	Dolomite									50	53	28							
		86.7'										100	125	145							
												150	171	150							
	8	86.7'-	Dolomite							R/smR	47°				500	64,250		1.35	2.77		173.6
		83.3'		14,920	1.89										1000	66,000					
	11	76.65'-	Dolomite	20,839	2.52										600	67,650		0.64	2.77		175.1
		73.5'													1200	71,600					

ShR = Sheared Rock Surface   G/roR = Grout on rough Rock Surface, Cured 7 days.
R/smR = Smooth Rock Surface   G/SmR = Grout on Smooth Rock Surface, Cured 7 days.

ORD Form
1 April 75 975

ED-FL

Table 9b

AD-A112 306 TIPPETTS-ABBETT-MCCARTHY-STRATTON NEW YORK F/G 13/2
ST. LAWRENCE SEAWAY ADDITIONAL LOCKS STUDY. GEOTECHNICAL REPORT--ETC(U)
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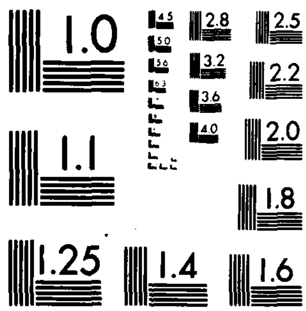


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table 10
EISENHOWER "TWIN" LOCK

Summary of Pressure Test Results

Boring No.	Depth of Packer (ft)		Pressure (psi)			Flow (gpm)	Strati-graphic Units
	Top	Bottom	Gage	Static	Actual		
UDC-681201	103.1	108.1	50.0	46.8	97.0	26.0	13
	100.0	108.1	50.0	45.0	95.0	25.0	13
	89.0	108.1	47.6	41.4	89.0	32.0	13
UDC-681202	96.0	99.3	50.0	44.3	94.3	27.0	13
	91.0	96.0	48.8	42.2	91.0	27.0	13-16
	86.0	91.0	43.8	42.2	86.0	4.6	16
	81.0	86.0	43.0	38.0	81.0	1.8	16-18
	76.0	81.0	38.0	38.0	76.0	0.0	18-20
	71.0	76.0	37.0	34.0	71.0	1.4	20-22
	70.0	75.0	36.0	34.0	70.0	0.0	20-22
C-681203	201.0	205.1	50.0	93.6	143.6	0.0	4- 6
	196.0	201.0	50.0	89.3	139.3	0.0	6- 8
	191.0	196.0	50.0	89.3	139.3	0.0	8-10
	186.0	191.0	50.0	84.9	134.9	0.0	10
	181.0	186.0	50.0	84.9	134.9	0.0	10-11
	176.0	181.0	50.0	80.6	130.6	0.0	11-12
	171.0	176.0	50.0	80.6	130.6	0.0	13
	166.0	171.0	50.0	76.2	126.2	19.4	13
	161.0	166.0	50.0	76.2	126.2	23.4	13
	156.0	161.0	50.0	71.9	121.9	16.2	13
	151.0	156.0	50.0	71.9	121.9	25.0	13
	146.0	151.0	50.0	67.6	117.6	10.6	13-15
	141.0	146.0	50.0	67.6	117.6	17.2	15-17
	136.0	141.0	50.0	63.2	113.2	17.8	17
	131.0	136.0	50.0	58.9	108.9	18.8	17-19
	126.0	131.0	50.0	58.9	108.9	8.6	19-20
	121.0	126.0	50.0	58.9	108.9	7.2	20-22
	116.0	121.0	50.0	54.5	104.5	8.4	22-24
	111.0	116.0	50.0	54.5	104.5	11.6	24-25
	106.0	111.0	50.0	50.2	100.2	2.0	25
	101.0	106.0	50.0	50.2	100.2	2.4	25-26

Table 10 (cont'd)

EISENHOWER "TWIN" LOCK

Summary of Pressure Test Results

Boring No.	Depth of Packer (ft)		Pressure (psi)			Flow (gpm)	Strati-graphic Units
	Top	Bottom	Gage	Static	Actual		
C-681204	208.0	211.0	50.0	93.6	143.6	0.0	8- 9
	203.0	208.0	50.0	89.3	139.3	0.0	9-10
	198.0	203.0	50.0	89.3	139.3	0.0	10-11
	193.0	198.0	50.0	84.9	134.9	0.0	11-12
	188.0	193.0	50.0	84.9	134.9	0.0	12-13
	183.0	188.0	50.0	81.6	131.6	1.1	13
	178.0	183.0	50.0	81.6	131.6	22.6	13
	173.0	178.0	50.0	76.2	126.2	22.2	13
	168.0	173.0	50.0	76.2	126.2	24.4	13
	166.0	171.0	50.0	76.2	126.2	24.6	13-14
	161.6	166.6	50.0	71.9	121.9	12.4	14-15
	156.6	161.6	50.0	71.9	121.9	7.4	15-16
	151.6	156.6	50.0	71.9	121.9	22.4	16-17
	146.6	151.6	50.0	67.6	117.6	22.2	17-19
	141.6	146.6	50.0	67.6	117.6	8.4	19-20
	136.6	141.6	50.0	63.2	113.2	6.4	20-22
	131.6	136.6	50.0	63.2	113.2	6.6	22-24
	126.6	131.6	50.0	58.9	108.9	9.0	24-25
	121.6	126.6	50.0	58.9	108.9	10.8	25
	116.6	121.6	50.0	54.5	104.5	1.5	25-26
	111.6	116.6	50.0	54.5	104.5	10.0	26-27
C-681205	176.0	179.0	50.0	80.6	130.6	1.0	2
	171.0	176.0	50.0	76.3	126.3	3.0	2- 3
	166.0	171.0	50.0	76.3	126.3	5.6	3- 4
	161.0	166.0	50.0	71.9	121.9	0.0	5
	156.0	161.0	50.0	71.9	121.9	0.0	5- 7
	151.0	156.0	50.0	67.6	117.6	21.3	7- 9
	146.0	151.0	50.0	67.6	117.6	2.6	10
	141.0	146.0	50.0	63.3	113.3	0.0	10-11
	136.0	141.0	50.0	63.3	113.3	0.0	11-12
	131.0	136.0	50.0	58.9	108.9	0.0	13
	126.0	131.0	50.0	58.9	108.9	20.2	13
	121.0	126.0	50.0	54.6	104.6	16.8	13
	116.0	121.0	50.0	54.6	104.6	2.0	13
	101.0	106.0	50.0	45.9	95.9	25.4	16
	96.0	101.0	50.0	45.9	95.9	17.8	16-18
	91.0	96.0	49.5	41.5	91.0	21.4	18-20
	86.0	91.0	44.5	41.5	86.0	23.5	20-22

Table 10 (cont'd)
EISENHOWER "TWIN" LOCK

Summary of Pressure Test Results

Boring No.	Depth of Packer (ft)		Pressure (psi)			Flow (gpm)	Strati-graphic Units
	Top	Bottom	Gage	Static	Actual		
C-681207	198.5	201.7	50.0	89.3	139.3	0.0	2- 3
	193.5	198.5	50.0	84.9	134.9	0.0	3- 4
	188.5	193.5	50.0	84.9	134.9	0.0	4- 5
	183.5	188.5	50.0	84.9	134.9	0.0	5- 7
	178.5	183.5	50.0	80.6	130.6	0.0	7- 9
	173.5	178.5	50.0	80.6	130.6	0.0	9-10
	168.5	173.5	50.0	76.3	126.3	0.5	10-11
	163.5	168.5	50.0	76.3	126.3	0.0	11-12
	158.5	163.5	50.0	71.9	121.9	0.3	12-13
	153.5	158.5	50.0	71.9	121.9	4.5	13
	148.5	153.5	50.0	67.6	117.6	22.8	13
	143.5	148.5	50.0	67.6	117.6	24.0	13
	138.5	143.5	50.0	63.3	113.3	16.8	13
	131.5	136.5	50.0	63.3	113.3	25.4	14-15
	126.5	131.5	50.0	63.3	113.3	25.8	15-16
	121.5	126.5	50.0	63.3	113.3	24.2	16-17
	116.5	121.5	50.0	58.9	108.9	13.0	17-19
	111.5	116.5	50.0	58.9	108.9	18.0	19-20
	106.5	111.5	50.0	54.6	104.6	13.8	21-22
	101.5	106.5	46.9	54.6	101.5	13.0	22-24
AC-681208	172.0	175.5	50.0	76.3	126.3	0.0	0- 1
	166.9	171.9	50.0	76.3	126.3	10.7	1
	161.9	166.9	50.0	76.3	126.3	11.0	1- 2
	156.9	161.9	50.0	71.9	121.9	15.0	2
	151.9	156.9	50.0	71.9	121.9	11.4	2
	146.9	151.9	50.0	67.6	117.6	9.5	2- 3
	141.9	146.9	50.0	67.6	117.6	8.7	3- 4
	136.9	141.9	50.0	63.2	113.2	6.5	4- 5
	131.9	136.9	50.0	63.2	113.2	6.6	5- 7
	126.9	131.9	50.0	58.9	108.9	5.6	7- 9
	121.9	126.9	50.0	58.9	108.9	6.0	9-10
	116.9	121.9	50.0	54.5	104.5	5.7	10-11
	111.9	116.9	50.0	54.5	104.5	2.6	11-12
	106.9	111.9	50.0	50.2	100.2	23.4	12-13
	101.9	106.9	50.0	50.2	100.2	25.2	13
	96.9	101.9	50.0	45.9	95.9	9.4	13
	91.9	96.9	46.0	45.9	91.9	5.83	13
	86.9	91.9	45.4	41.5	86.9	1.0	13
	81.9	86.9	40.4	41.5	81.9	10.2	13-16

Table 10 (cont'd)
EISENHOWER "TWIN" LOCK

Summary of Pressure Test Results

Boring No.	Depth of Packer (ft)		Pressure (psi)			Flow (gpm)	Strati-graphic Units
	Top	Bottom	Gage	Static	Actual		
AC-681209	188.2	193.2	50.0	89.3	139.3	18.8	2
	183.2	188.2	50.0	89.3	139.3	8.2	2
	178.2	183.2	50.0	80.6	130.6	8.2	2
	173.2	178.2	50.0	80.6	130.6	5.7	2- 4
	168.2	173.2	50.0	80.6	130.6	3.6	4- 5
C-681210	203.2	205.2	50.0	89.3	139.3	0.0	10
	198.2	203.2	50.0	89.3	139.3	0.0	10-11
	193.2	198.2	50.0	89.3	139.3	0.0	11-12
	188.2	193.2	50.0	85.0	135.0	0.0	12-13
	183.2	188.2	50.0	85.0	135.0	7.3	13
	178.2	183.2	50.0	80.7	130.7	20.3	13
	173.2	178.2	50.0	80.7	130.7	5.0	13
	168.2	173.2	50.0	76.4	126.4	24.3	13
	163.2	168.2	50.0	76.4	126.4	2.3	13-15
	158.2	163.2	50.0	72.1	122.1	0.0	15-16
	153.2	158.2	50.0	72.1	122.1	24.0	16
	148.2	153.2	50.0	67.8	117.8	25.0	17-18
	143.2	148.2	50.0	67.8	117.8	0.0	19-20
	138.2	143.2	50.0	63.5	113.5	2.0	20-22
	133.2	138.2	50.0	63.5	113.5	0.0	22-24
	128.2	133.2	50.0	59.2	109.2	1.6	24-25
	123.2	128.2	50.0	59.2	109.2	3.6	25
	118.2	123.2	50.0	54.9	104.9	1.6	25-26
	113.2	118.2	50.0	54.9	104.9	6.6	26-27
C-681211	204.0	209.0	50.0	88.5	138.5	0.0	6- 8
	199.0	204.0	50.0	88.5	138.5	0.0	8-10
	194.0	199.0	50.0	88.5	138.5	0.0	10-11
	189.0	194.0	50.0	88.5	138.5	0.0	11
	184.0	189.0	50.0	79.8	129.8	0.0	11-13
	179.0	184.0	50.0	79.8	129.8	11.6	13
	174.0	179.0	50.0	79.8	129.8	3.0	13
	169.0	174.0	50.0	79.8	129.8	22.0	13
	164.0	169.0	50.0	71.1	121.1	25.0	13
	159.0	164.0	50.0	71.1	121.1	25.0	13-14
	154.0	159.0	50.0	71.1	121.1	2.0	14-15
	149.0	154.0	50.0	71.1	121.1	5.0	15-16
	144.0	149.0	50.0	71.1	121.1	6.0	16-17
	139.0	144.0	50.0	62.4	112.4	0.0	17-19
	134.0	139.0	50.0	62.4	112.4	3.0	19-20
	129.0	134.0	50.0	62.4	112.4	3.0	20-22
	124.0	129.0	50.0	62.4	112.4	1.0	22-24
	119.0	124.0	50.0	53.7	103.7	3.0	24-25
	114.0	119.0	50.0	53.7	103.7	3.5	25

Table 11
SNELL "TWIN" LOCK
Summary of Pressure Test Results

Boring No.	Depth of Packer (ft)		Pressure (psi)			Flow (gpm)	Strati-graphic Units
	Top	Bottom	Gage	Static	Actual		
C-701301	164.3	169.3	50	71.3	121.3	0.0	7-10
	161.8	166.8	50	70.2	120.2	0.0	9-10
	156.8	161.8	50	68.0	118.0	0.0	10-11
	151.8	156.8	50	65.8	115.8	0.03	11
	146.8	151.8	50	63.6	113.6	0.33	11-13
	141.8	146.8	50	61.4	111.4	1.63	13
	136.8	141.8	50	59.2	109.2	0.66	13
	131.8	136.8	50	57.0	107.0	1.93	13
	126.8	131.8	50	54.8	104.8	1.4	13-14
	121.8	126.8	50	52.6	102.6	16.3	14-16
	111.8	116.8	50	48.2	98.2	13.2	16-17
	106.8	111.8	50	46.0	96.0	9.0	18-19
	101.8	106.8	50	43.8	93.8	7.13	19-21
	96.8	101.8	50	41.6	91.6	6.66	21-22
	91.8	96.8	50	39.4	89.4	5.26	22-24
	86.8	91.8	49.6	37.2	86.8	7.3	24-25
	81.8	86.8	46.8	35.0	81.8	7.5	25
	78.8	83.8				15.66	25-26
C-701302	167.8	172.8	50	70.7	120.7	0.0	7- 9
	162.8	167.8	50	68.5	118.5	0.0	9-10
	157.8	162.8	50	66.3	116.3	0.0	10-11
	152.8	157.8	50	64.1	114.1	0.1	11
	147.8	152.8	50	61.9	111.9	0.33	11-13
	142.8	147.8	50	59.7	109.7	0.4	13
	137.8	142.8	50	57.5	107.5	0.33	13
	132.8	137.8	50	55.3	105.3	0.0	13
	127.8	132.8	50	53.1	103.1	13.5	13
	122.8	127.8	50	50.9	100.9	16.5	13-15
	117.8	122.8	50	48.7	98.7	0.85	15-16
	112.8	117.8	50	46.5	96.5	0.5	16-18
	107.8	112.8	50	44.3	94.3	1.7	18-19
	102.8	107.8	50	42.1	92.1	0.6	20-21
	97.8	102.8	50	39.9	89.9	5.0	21-22
	92.8	97.8	50	37.7	87.7	7.3	22-24
	87.8	92.8	50	35.5	85.5	9.6	24-25
	82.8	87.8	50	33.3	83.3	17.5	25
	77.8	82.8	45	31.1	76.1	14.1	25-26

Table 11 (cont'd)
SNELL "TWIN" LOCK
Summary of Pressure Test Results

Boring No.	Depth of Packer (ft)		Pressure (psi)			Flow (gpm)	Strati-graphic Units
	Top	Bottom	Gage	Static	Actual		
C-701303	167.9	172.9	50	78.0	128.0	0.0	6- 8
	168.9	171.9	50	78.0	128.0	0.0	7- 8
	163.9	168.9	50	73.7	123.7	0.0	8-10
	158.9	163.9	50	73.7	123.7	0.0	10-11
	153.9	158.9	50	69.4	119.4	0.0	11
	148.9	153.9	50	69.4	119.4	0.0	11-13
	143.9	148.9	50	65.1	115.1	0.0	13
	138.9	143.9	50	65.1	115.1	0.0	13
	133.9	138.9	50	60.8	110.8	0.26	13
	128.9	133.9	50	60.8	110.8	16.9	13
	123.9	128.9	50	56.5	106.5	14.3	13-15
	118.9	123.9	50	56.5	106.5	1.0	15-16
	113.9	118.9	50	52.2	102.2	0.5	16-17
	108.9	113.9	50	52.2	102.2	0.33	17-19
	103.9	108.9	50	47.9	97.9	1.0	19-20
	98.9	103.9	50	47.9	97.9	12.0	20-22
	93.9	98.9	50	43.6	93.6	1.2	22-24
	88.9	93.9	45	43.6	88.6	2.16	24-25
	83.9	88.9	45	39.3	84.3	16.0	25
	79.9	84.9	40	39.3	79.3	19.5	25-26
C-701304	159.4	164.4	50	71.8	121.8	0.0	1
	156.4	161.4	50	71.8	121.8	0.1	1- 2
	151.4	156.4	50	67.5	117.5	0.2	2
	146.4	151.4	50	67.5	117.5	0.23	2
	141.4	146.4	50	63.2	113.2	2.1	2- 3
	136.4	141.4	50	63.2	113.2	0.7	3- 5
	131.4	136.4	50	58.9	108.9	1.3	5- 6
	126.4	131.4	50	58.9	108.9	0.76	6- 8
	121.4	126.4	50	54.6	104.6	1.8	8-10
	116.4	121.4	50	54.6	104.6	0.83	10-11
	111.4	116.4	50	50.3	100.3	1.03	11
	106.4	111.4	50	50.3	100.3	0.93	11-13
	101.4	106.4	50	46.3	96.3	0.26	13
	96.4	101.4	50	46.3	96.3	0.0	13
	91.4	96.4	45	42.3	87.3	0.33	13
	86.4	91.4	45	42.3	87.3	0.33	13
	81.4	86.4	40	38.0	78.0	14.0	13-15
	76.4	81.4	40	38.0	78.0	7.3	15-16
	71.4	76.4	35	33.7	68.7	14.5	16
	68.4	72.4	35	33.7	68.7	15.0	16-18

Table 11 (cont'd)
SNELL "TWIN" LOCK

Summary of Pressure Test Results

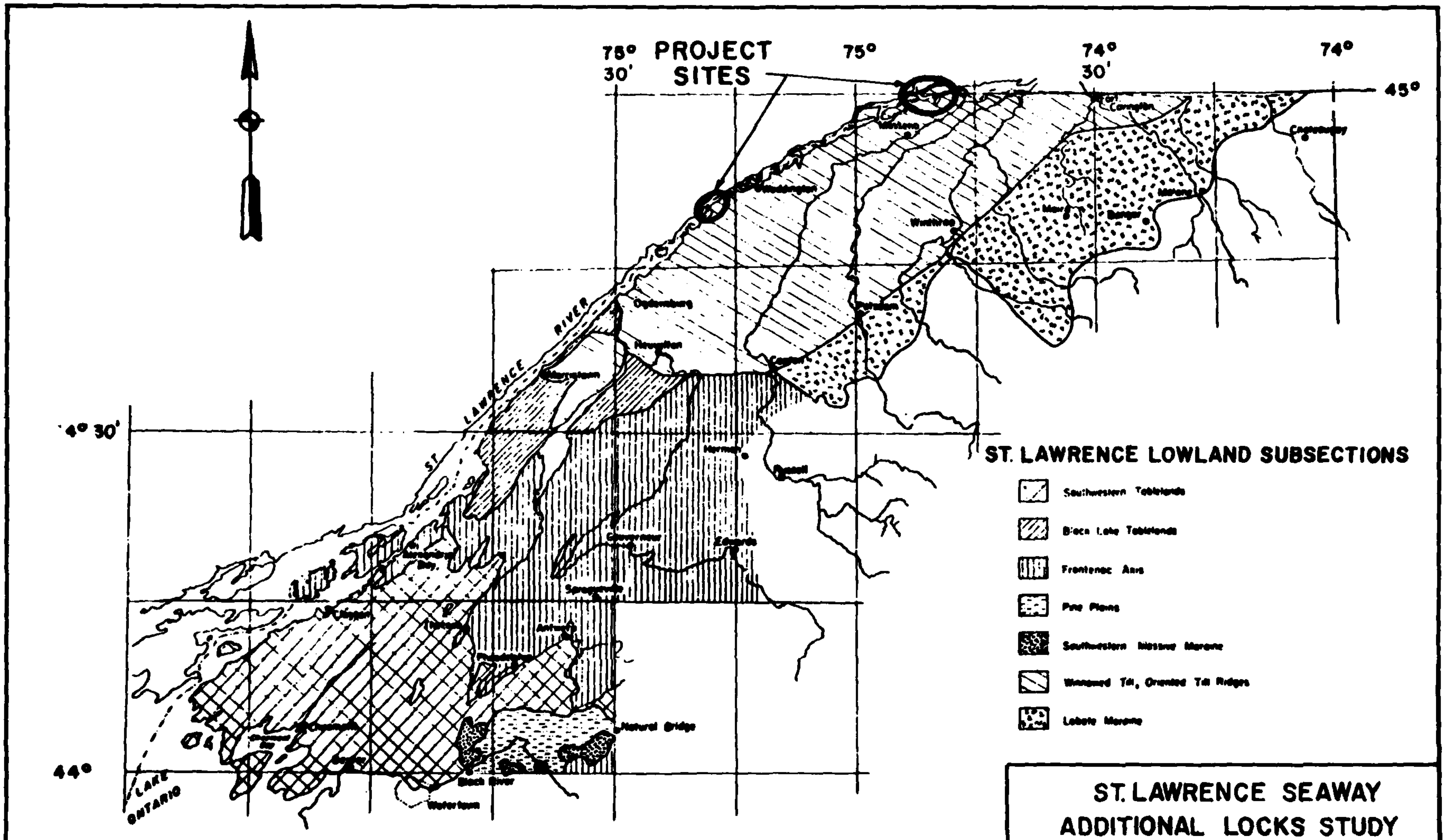
Boring No.	Depth of Packer (ft)		Pressure (psi)			Flow (gpm)	Strati-graphic Units
	Top	Bottom	Gage	Static	Actual		
C-701305	144.3	149.3	50	63.5	113.5	0.0	2
	141.3	146.3	50	63.5	113.5	0.0	2- 4
	136.3	141.3	50	63.5	113.5	0.0	4- 5
	131.3	136.3	50	59.2	109.2	6.6	5- 6
	126.3	131.3	50	59.2	109.2	2.0	6- 9
	121.3	126.3	50	54.9	104.9	0.5	9-10
	116.3	121.3	50	54.9	104.9	1.0	10-11
	111.3	116.3	50	50.6	100.6	0.0	11
	106.3	111.3	50	50.6	100.6	8.6	11-13
	101.3	106.3	50	46.3	96.3	1.16	13
	96.3	101.3	50	46.3	96.3	11.6	13
	91.3	96.3	50	42.0	92.0	3.5	13
	86.3	91.3	45	42.0	92.0	10.5	13
	81.3	86.3	45	37.7	82.7	12.0	13-15
	76.3	81.3	40	37.7	77.7	12.16	15-16
	71.3	76.3	35	33.4	68.4	9.6	16-17
	66.3	71.3	30	33.4	63.4	0.0	17-19
	61.3	66.3	30	29.1	59.1	0.0	19-20
	57.3	62.3	30	29.1	59.1	10.8	20-22
UC-701306	144.5	149.5	50	63.6	113.6	0.0	2
	142.5	147.5	50	63.6	113.6	0.0	2
	137.5	142.5	50	63.6	113.6	0.0	2- 3
	132.5	137.5	50	59.3	109.3	0.0	3- 4
	127.5	132.5	50	59.3	109.3	0.0	4- 5
	122.5	127.5	50	55.0	105.0	0.0	5- 7
	117.5	122.5	50	55.0	105.0	0.0	8-10
	112.5	117.5	50	50.7	100.7	0.0	10
	107.5	112.5	50	50.7	100.7	0.0	10-11
	102.5	107.5	50	46.4	96.4	2.0	11-12
	97.5	102.5	50	46.4	96.4	0.0	12-13
	92.5	97.5	50	42.1	92.1	0.0	13
	87.5	92.5	45	42.1	87.1	0.0	13
	82.5	87.5	45	37.8	82.8	0.0	13
	77.5	82.5	40	37.8	77.8	12.5	13
	72.5	77.5	40	33.5	73.5	10.0	13-16
	67.5	72.5	35	33.5	68.5	10.6	16
	62.5	67.5	35	29.2	64.2	0.0	16-18
	57.5	62.5	30	29.2	59.2	0.0	18-20

Table 11 (cont'd)
SNELL "TWIN" LOCK
Summary of Pressure Test Results

Boring No.	Depth of Packer (ft)		Pressure (psi)			Flow (gpm)	Strati-graphic Units
	Top	Bottom	Gage	Static	Actual		
C-701307	137.1	142.1	50	61.3	111.3	0.0	5- 7
	132.1	137.1	50	57.0	107.0	0.0	7- 9
	127.1	132.1	50	57.0	107.0	0.0	9-10
	122.1	127.1	50	52.7	102.7	0.0	10-11
	117.1	122.1	50	52.7	102.7	0.0	11-12
	112.1	117.1	50	48.4	98.4	0.0	12-13
	107.1	112.1	50	48.4	98.4	0.0	13
	102.1	107.1	50	44.1	94.1	0.0	13
	97.1	102.1	50	44.1	94.1	11.2	13
	92.1	97.1	50	39.8	89.8	13.8	13
	87.1	92.1	50	39.8	89.8	13.9	13-15
	82.1	87.1	45	35.5	80.5	10.2	15-16
	77.1	82.1	40	35.5	75.5	6.0	16-18
	72.1	77.1	35	31.2	66.2	0.0	18-20
	67.1	72.1	35	31.2	66.2	0.0	20-22
	62.1	67.1	30	26.9	56.9	0.0	22-23
	57.1	62.1	30	26.9	56.9	1.2	23-24
	52.1	57.1	30	22.6	52.6	9.0	24-25
C-701308	99.4	104.4	50	46.2	96.2	0.0	13
	97.4	102.4	50	46.2	96.7	14.1	13
	92.4	97.4	50	41.9	91.9	6.0	13-16
	87.4	92.4	45	41.9	86.9	12.0	16
	82.4	87.4	45	37.6	82.6	0.0	16-18
	77.4	82.4	40	37.6	77.6	0.0	18-20
	72.4	77.4	40	33.3	73.3	0.0	20-22
	67.4	72.4	35	33.3	68.3	0.0	22-23
	62.4	67.4	35	29.0	64.0	2.5	23-24
	57.4	62.4	30	29.0	59.0	15.5	24-25
C-701309	137.0	142.0	50	60.3	110.3	0.0	11
	134.5	139.5	50	56.0	106.0	7.5	11-13
	129.5	134.5	50	56.0	106.0	0.0	13
	124.5	129.5	50	51.7	101.7	5.2	13
	119.5	124.5	50	51.7	101.7	6.5	13
	114.5	119.5	50	47.4	97.4	5.0	13
	109.5	114.5	50	47.4	97.4	3.0	13-14
	104.5	109.5	50	43.1	93.1	6.5	14-16
	99.5	104.5	50	43.1	93.1	3.5	16-18
	94.5	99.5	50	38.8	88.8	5.5	18-20

Table 11 (cont'd)
SNELL "TWIN" LOCK
Summary of Pressure Test Results

Boring No.	Depth of Packer (ft)		Pressure (psi)			Flow (gpm)	Strati-graphic Units
	Top	Bottom	Gage	Static	Actual		
C-701310	80.6	85.6	45	35.8	80.8	0.8	15-16
	75.6	80.6	40	35.8	75.8	14.6	16-17
	70.6	75.6	40	31.5	71.5	0.0	17-19
	65.6	70.6	35	31.5	66.5	11.5	19-20
	60.6	65.6	30	27.2	57.2	0.0	20-22
	55.6	60.6	30	27.2	57.2	0.0	22-24
	50.6	55.6	25	22.9	47.9	0.0	24-25
	45.6	50.6	25	22.9	47.9	13.5	25



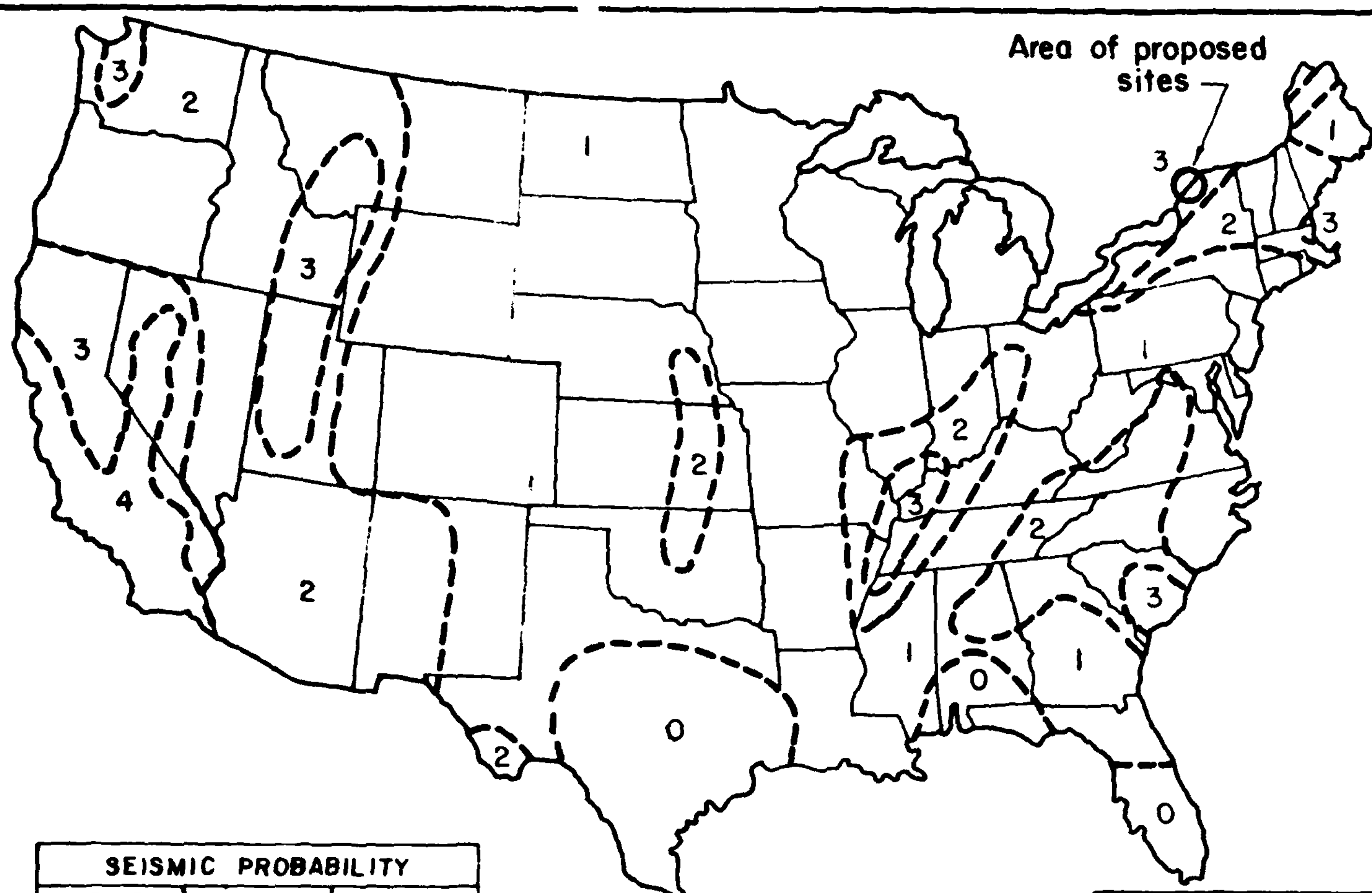
NOTE: MAP TAKEN FROM: MacCLINTOCK, PAUL AND DAVID P. STEWART, PLEISTOCENE GEOLOGY OF THE ST. LAWRENCE LOWLAND, N.Y. ST. MUSEUM, BULL. NO. 394, ALBANY, N.Y., 1965.

SCALE IN MILES

10 0 10 20

ST. LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY
ST. LAWRENCE VALLEY
PHYSIOGRAPHICAL PROVINCE

FIGURE 1

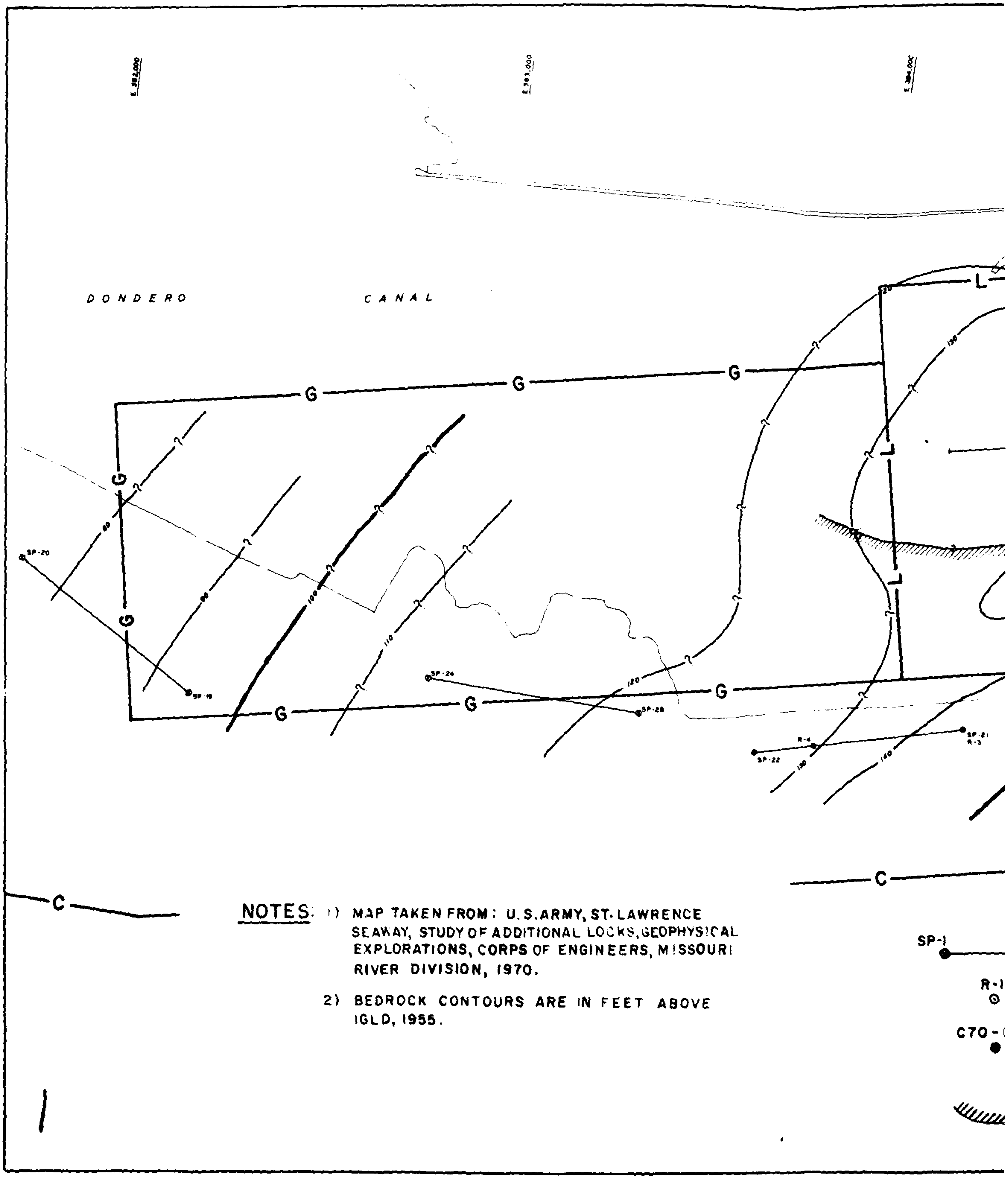


SEISMIC PROBABILITY		
ZONE	DAMAGE	COEFF
0	NONE	0
1	MINOR	0.025
2	MODERATE	0.05
3	MAJOR	0.10
4	GREAT	0.15

ST. LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

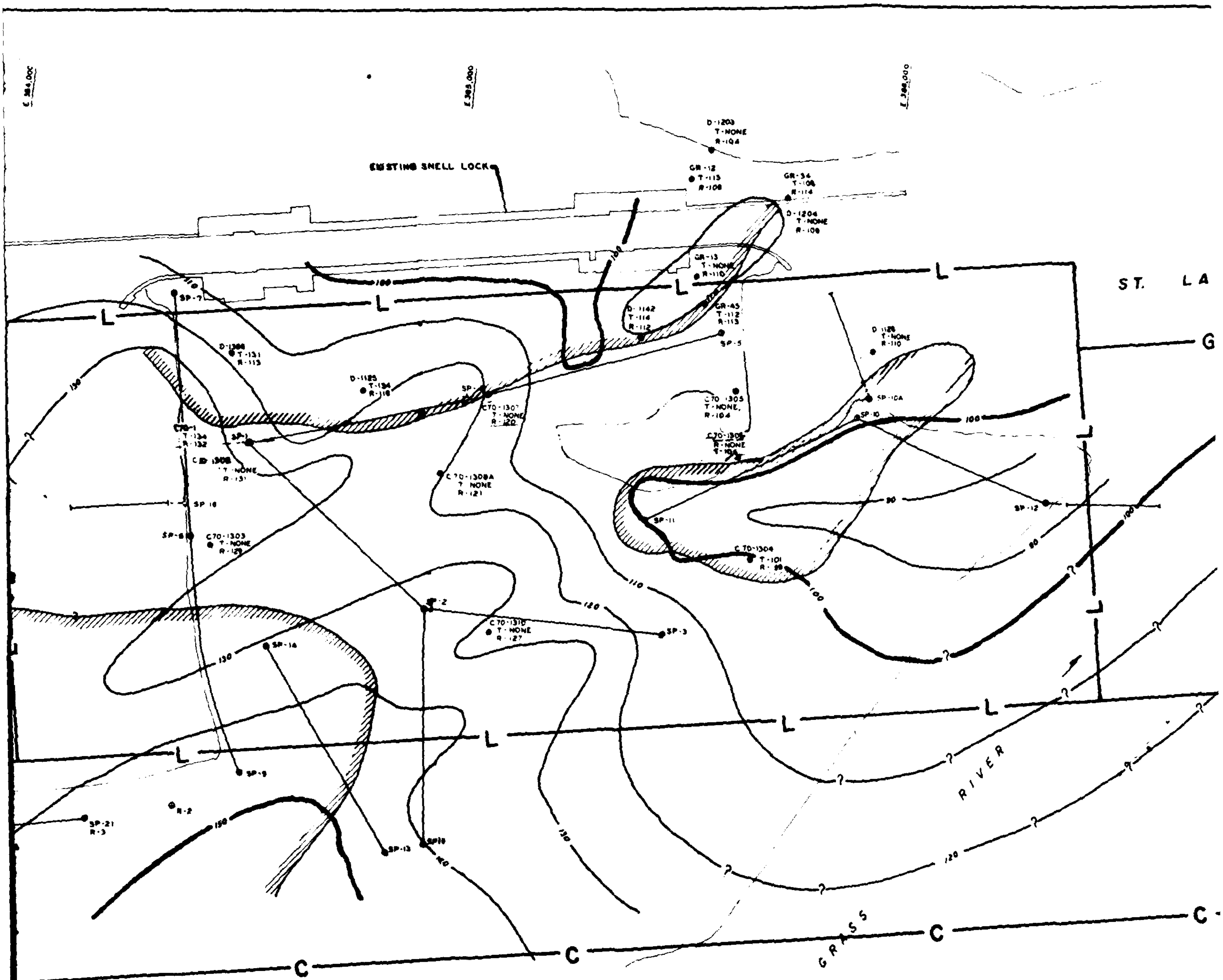
SEISMIC RISK MAP

FIGURE 2



NOTES: 1) MAP TAKEN FROM: U.S. ARMY, ST. LAWRENCE SEAWAY, STUDY OF ADDITIONAL LOCKS, GEOPHYSICAL EXPLORATIONS, CORPS OF ENGINEERS, MISSOURI RIVER DIVISION, 1970.

2) BEDROCK CONTOURS ARE IN FEET ABOVE IGLD, 1955.



LEGEND

SP-1 SP-2 — SEISMIC LINE AND SHOT POINT

R-1 — RESISTIVITY STATION

C70-1301 T-134 R-132 — DRILL HOLE W/ ELEVATION (IGLD, 1955) OF TILL AND BEDROCK

AREAL LIMITS OF TILL

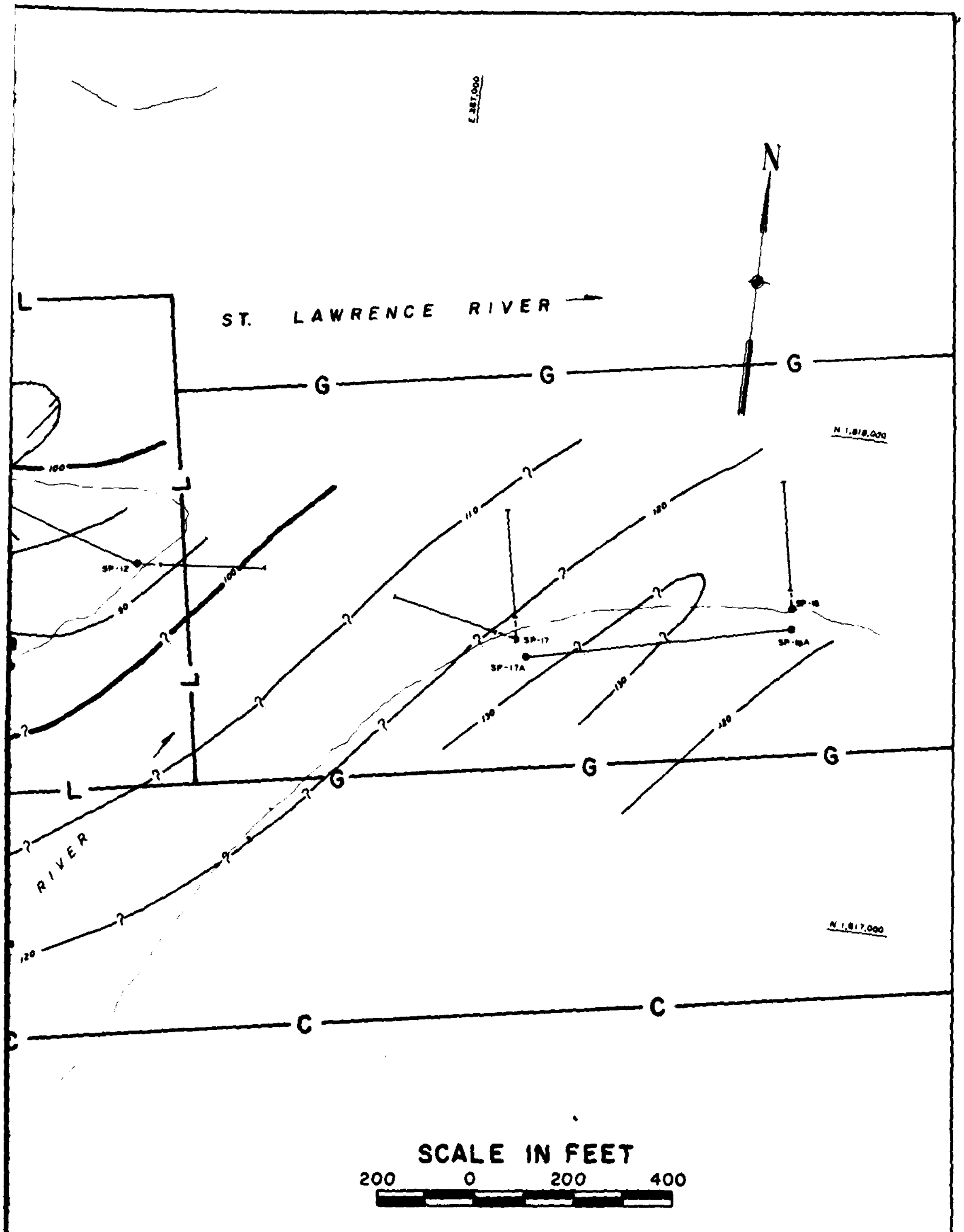
—L— LOCK AREA

—C— CHANNEL AREA

—G— GUIDE WALL AREA

VICINIT

2

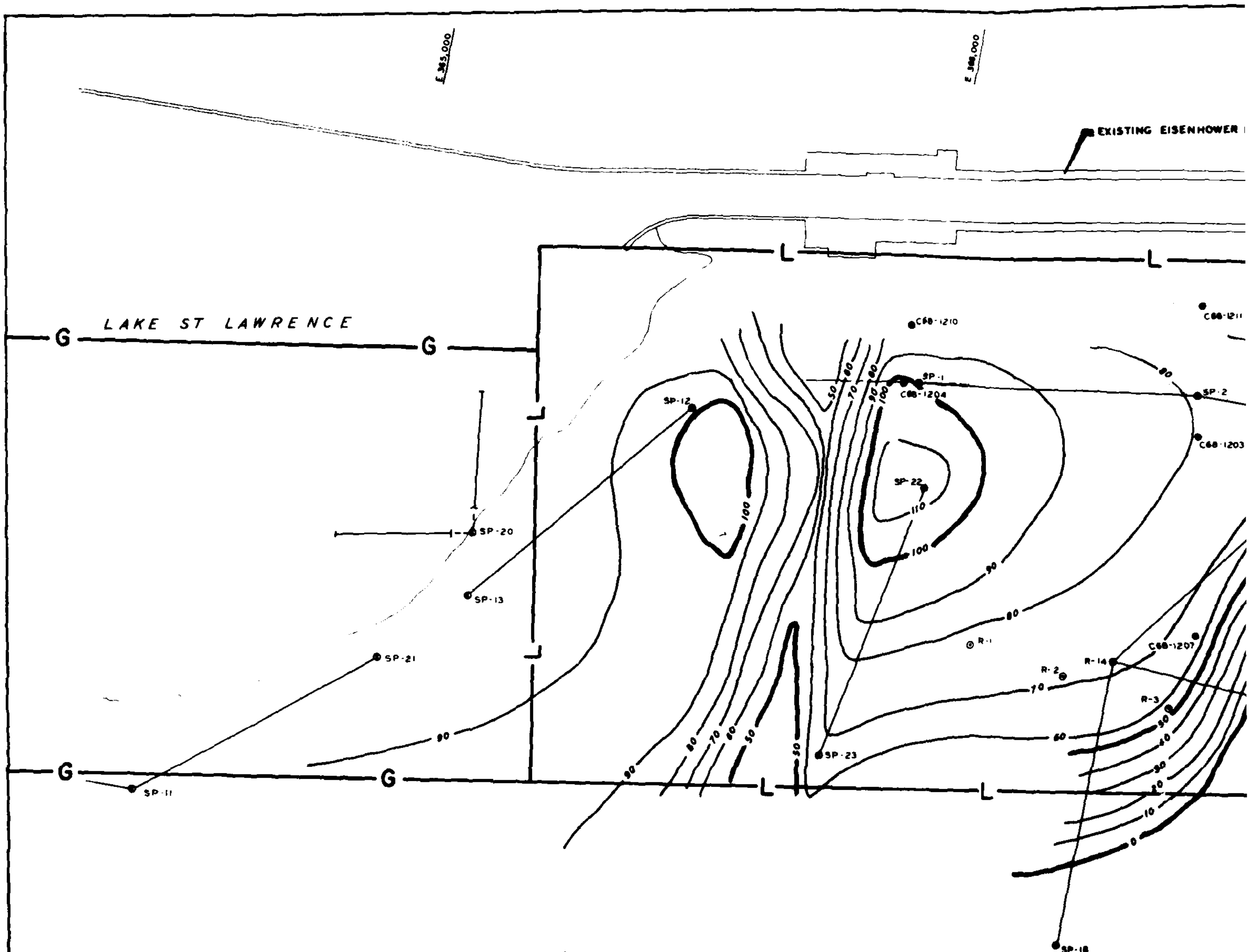


ST. LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

TOP OF ROCK CONTOUR MAP
VICINITY, SNELL "TWIN" LOCK ALTERNATIVE

3

FIGURE 3



NOTES:

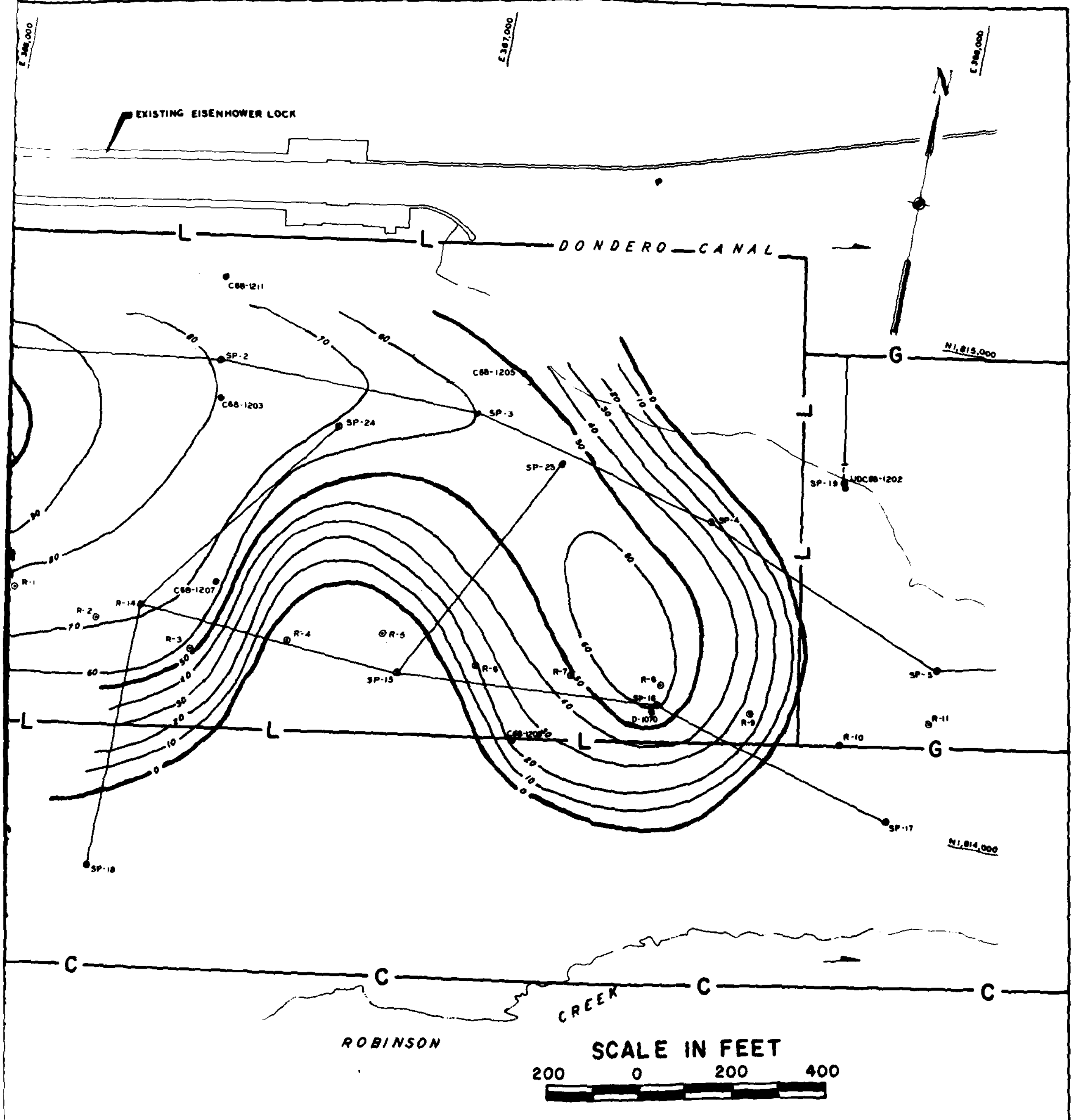
1) MAP TAKEN FROM U.S. ARMY, ST LAWRENCE SEAWAY, STUDY OF ADDITIONAL LOCKS, GEOPHYSICAL EXPLORATIONS, CORPS OF ENGINEERS MISSOURI RIVER DIVISION, 1970.

2) TILL ISOPACH LINES ARE IN FEET.

—C——C—

LEGEND

SP-1 ⊗——⊗ SP-2	SEISMIC LINE AND SHOT POINT	—L—	LOCK AREA
R-1 ⊙	RESISTIVITY STATION	—C—	CHANNEL AREA
C68-1205 ●	DRILL HOLE	—G—	GUIDE WALL AREA



REA

L AREA

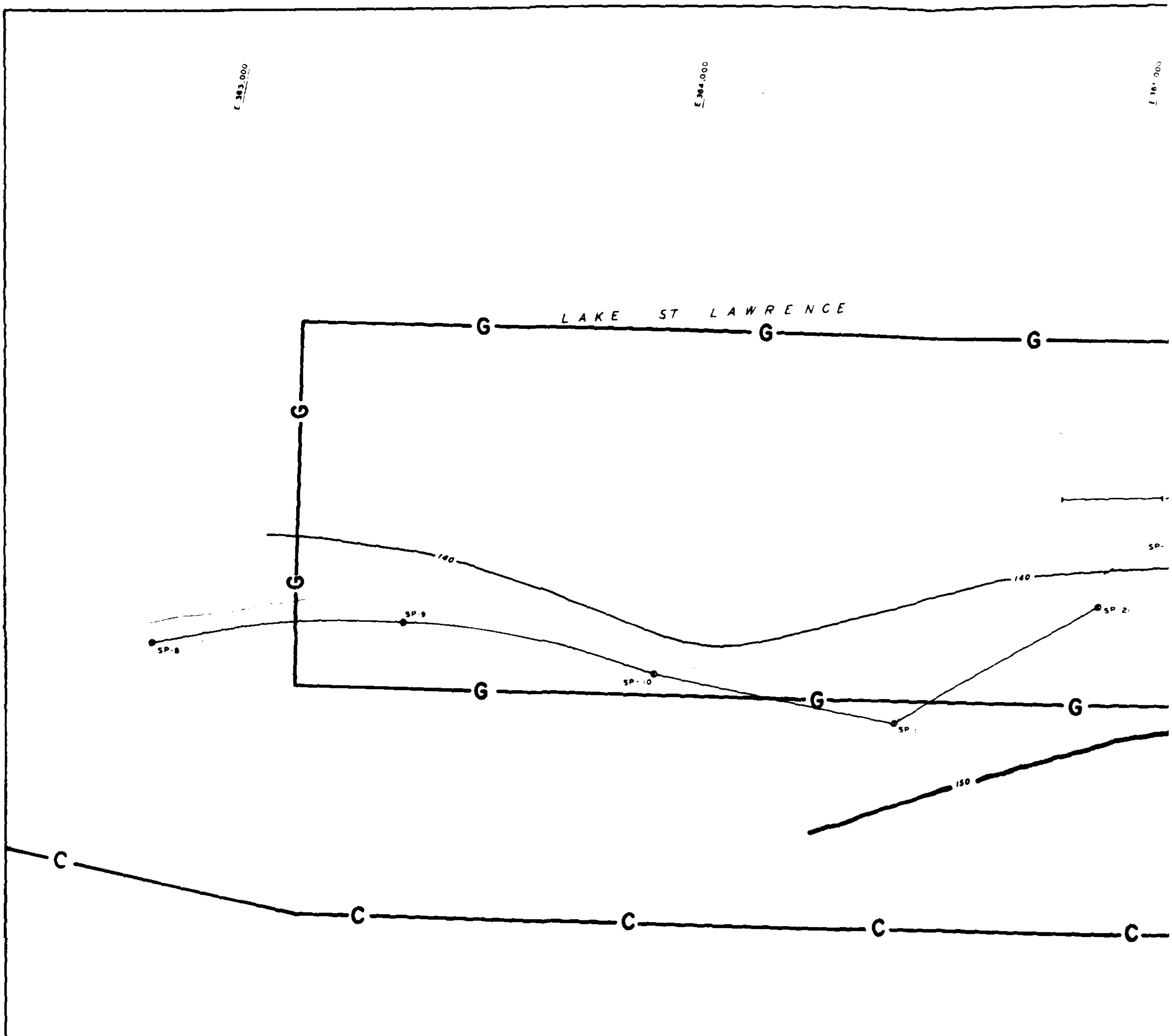
WALL AREA

ST. LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

TILL ISOPACH MAP
VICINITY, EISENHOWER "TWIN" LOCK ALTERNATIVE

2

FIGURE 4

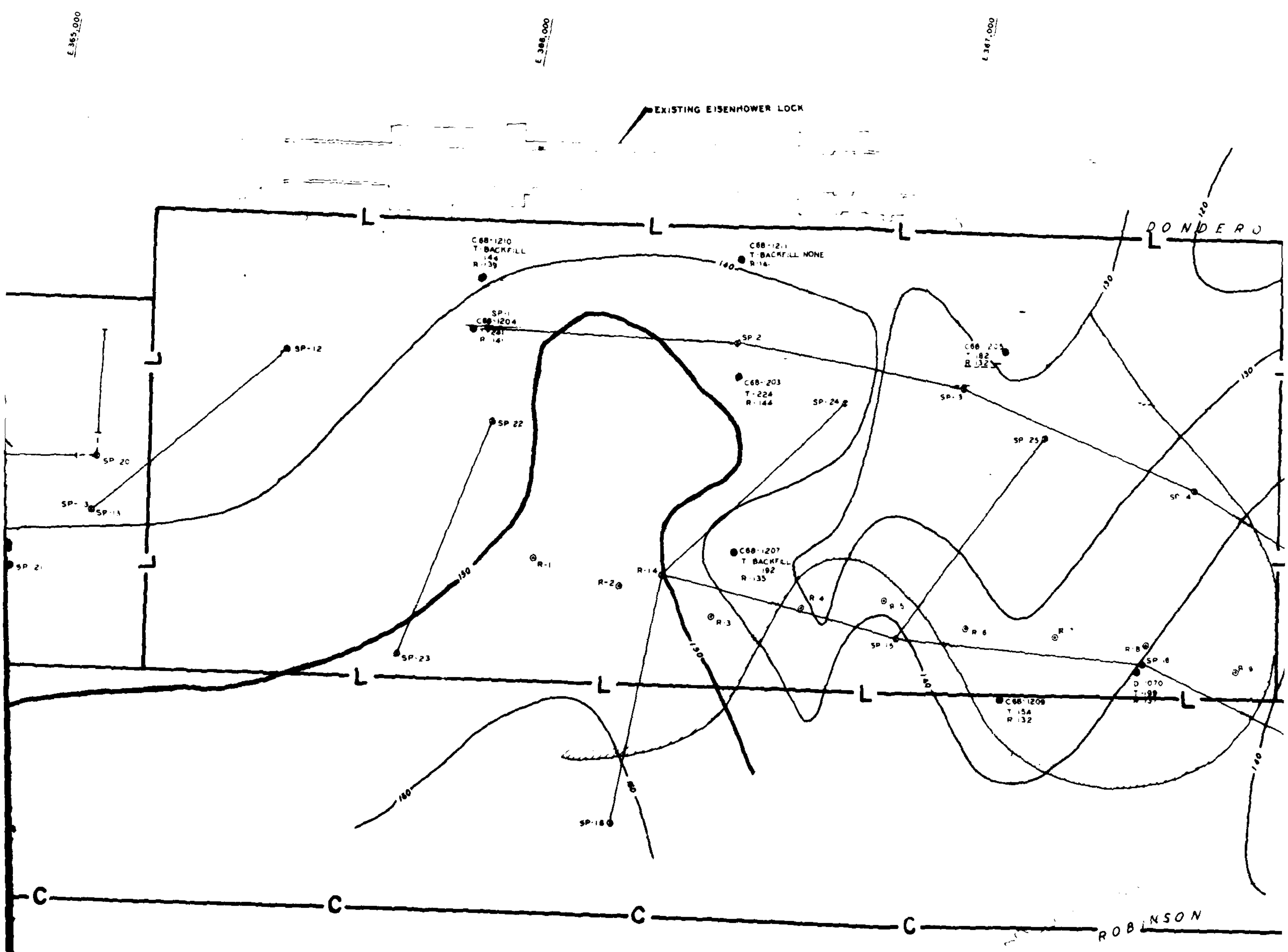


NOTES: 1) MAP TAKEN FROM: U.S.ARMY, ST. LAWRENCE SEAWAY, STUDY OF ADDITIONAL LOCKS, GEOPHYSICAL EXPLORATIONS, CORPS OF ENGINEERS, MISSOURI RIVER DIVISION, 1970.

2) BEDROCK CONTOURS ARE IN FEET ABOVE IGLD, 1955.

SP-1

R-1



LEGEND

SP-2 SEISMIC LINE AND SHOT POINT

R-1 RESISTIVITY STATION

C70-1301 T-134 R-132 DRILL HOLE W/ ELEVATION (IGLD, 1955) OF TILL AND BEDROCK

AREAL LIMITS OF TILL

2

—L— LOCK AREA

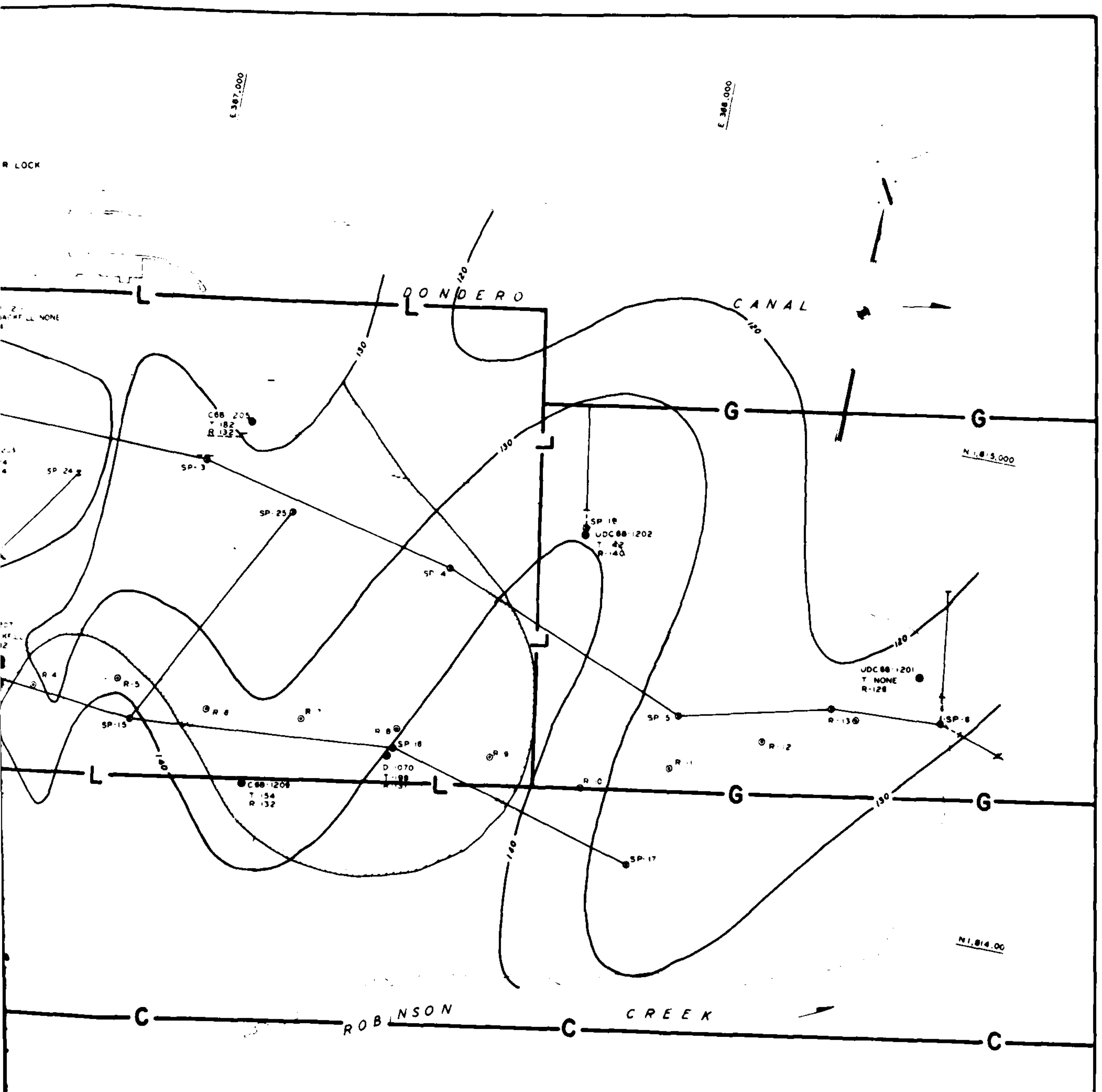
—C— CHANNEL AREA

—G— GUIDE WALL AREA

20

TOP

VICINITY, EISE



SCALE IN FEET

200 0 200 400

LOCK AREA

CHANNEL AREA

GUIDE WALL AREA

ST. LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

TOP OF ROCK CONTOUR MAP
VICINITY, EISENHOWER "TWIN" LOCK ALTERNATIVE

3

FIGURE 5

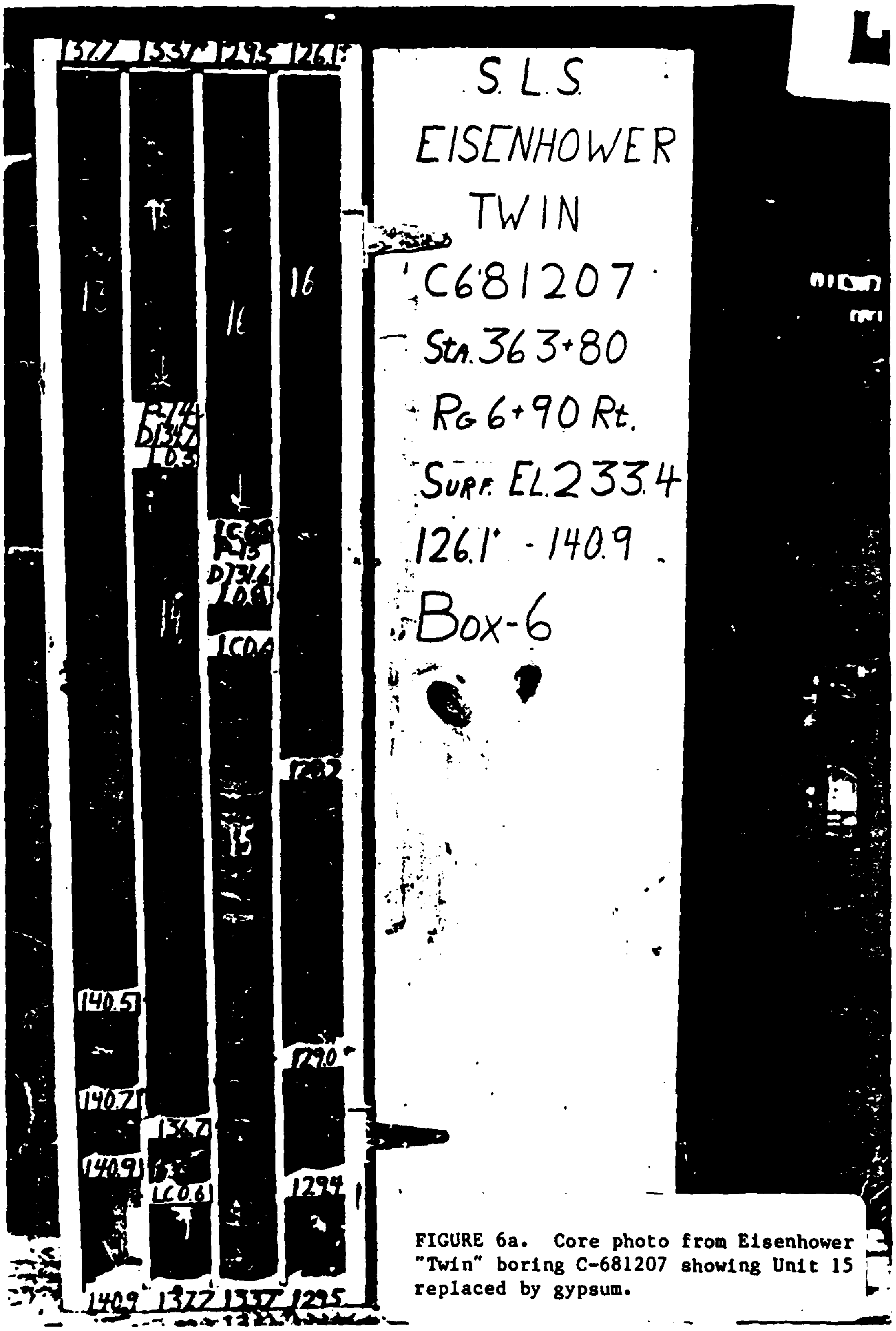


FIGURE 6a. Core photo from Eisenhower "Twin" boring C-681207 showing Unit 15 replaced by gypsum.

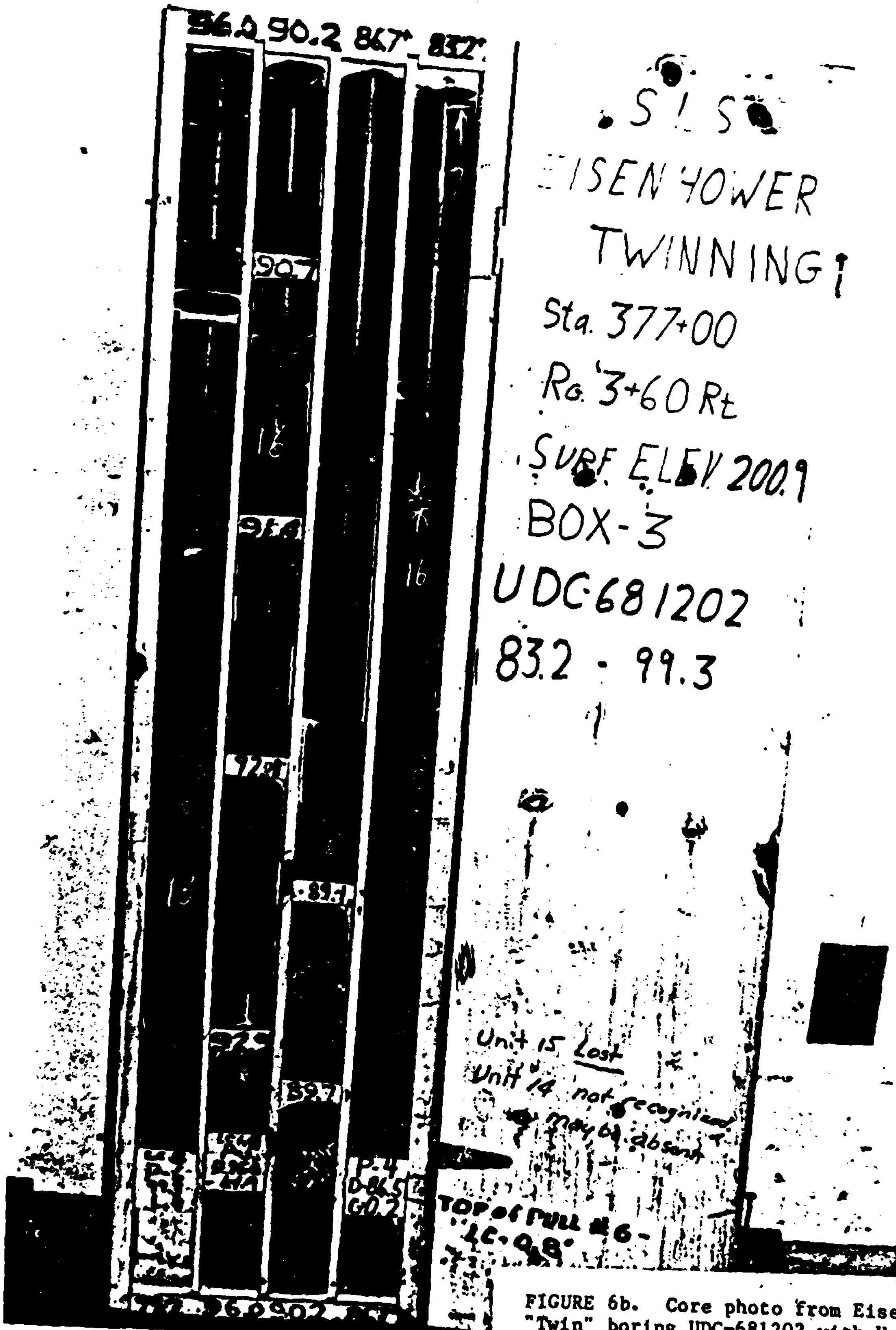


FIGURE 6b. Core photo from Eisenhower "Twin" boring UDC-681202 with Units 14 and 15 missing.

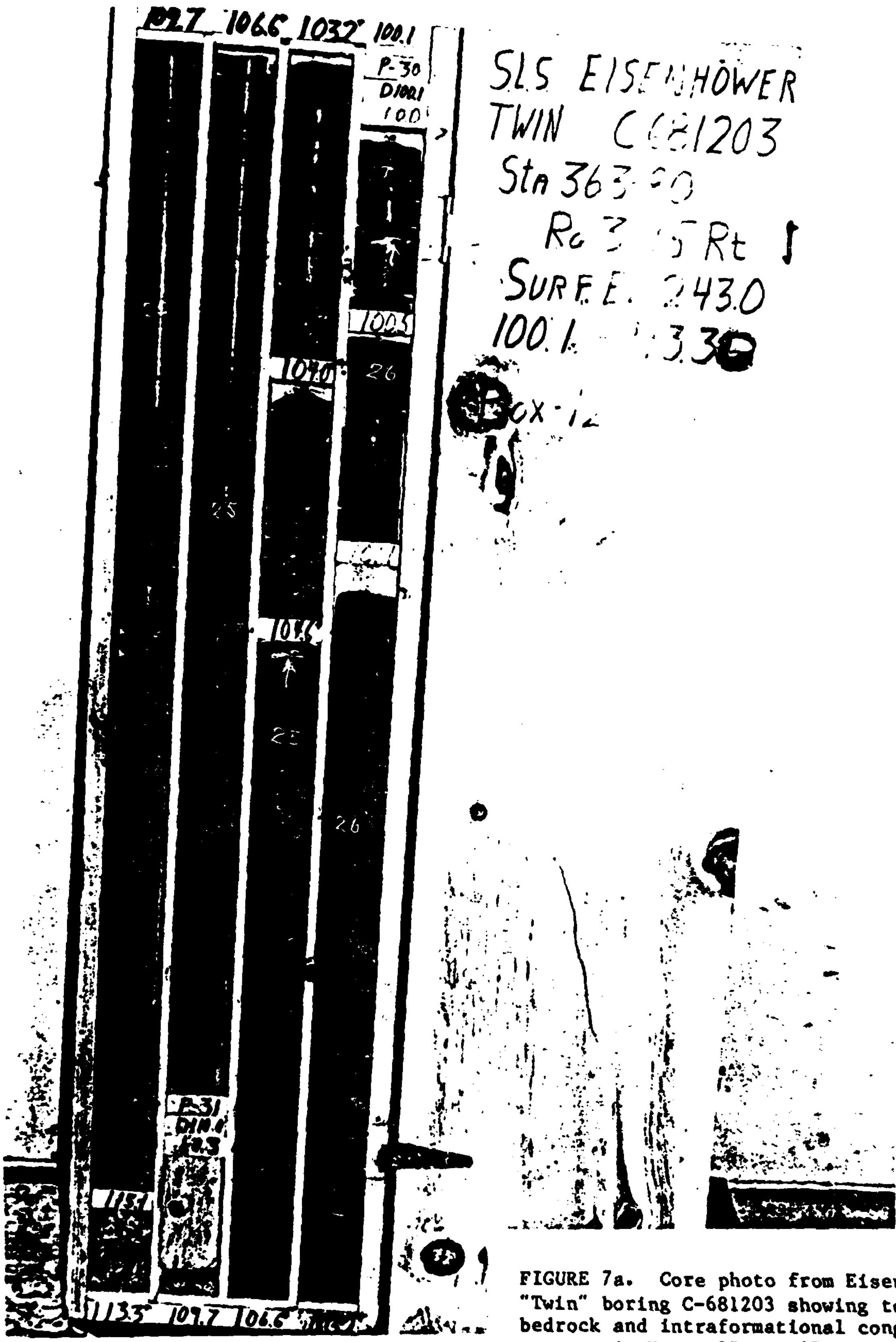


FIGURE 7a. Core photo from Eisenhower "Twin" boring C-681203 showing top of bedrock and intraformational conglomerates in Units 25 and 27.

FIGURE 7b. Core photo from Eisenhower "Twin" boring C-681205 showing Unit 5 replaced by gypsum.

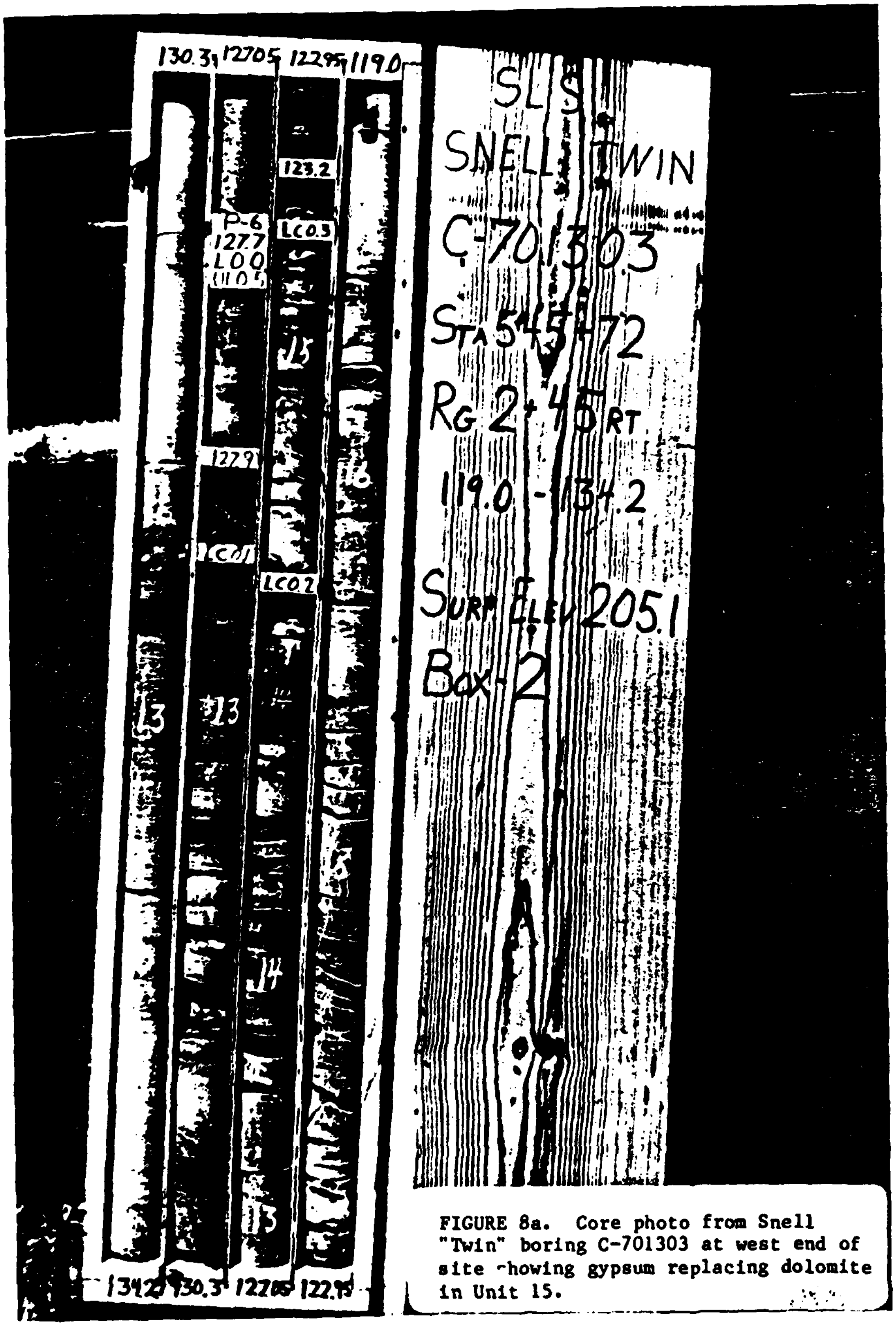


FIGURE 8a. Core photo from Snell "Twin" boring C-701303 at west end of site showing gypsum replacing dolomite in Unit 15.

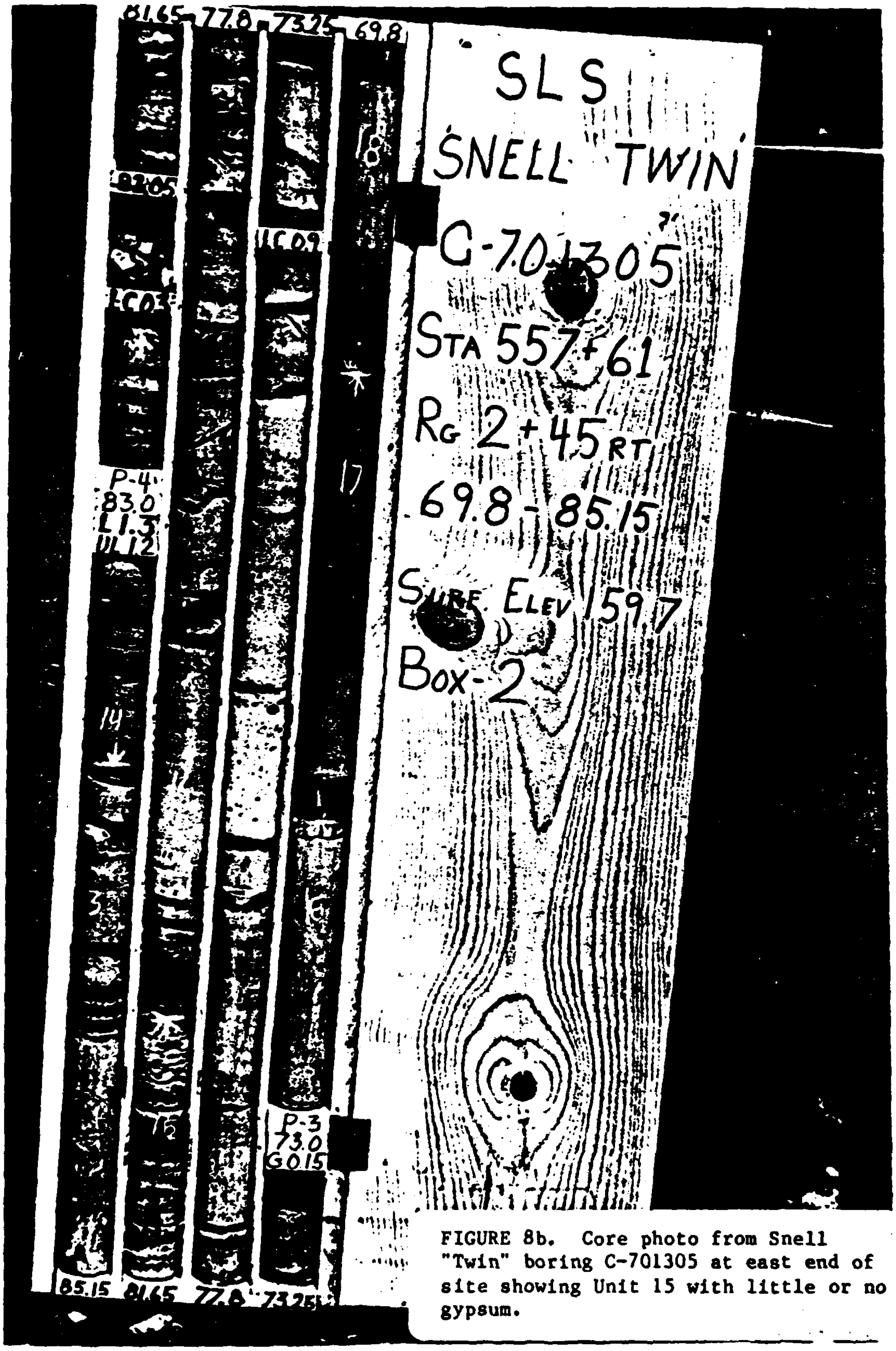


FIGURE 8b. Core photo from Snell "Twin" boring C-701305 at east end of site showing Unit 15 with little or no gypsum.

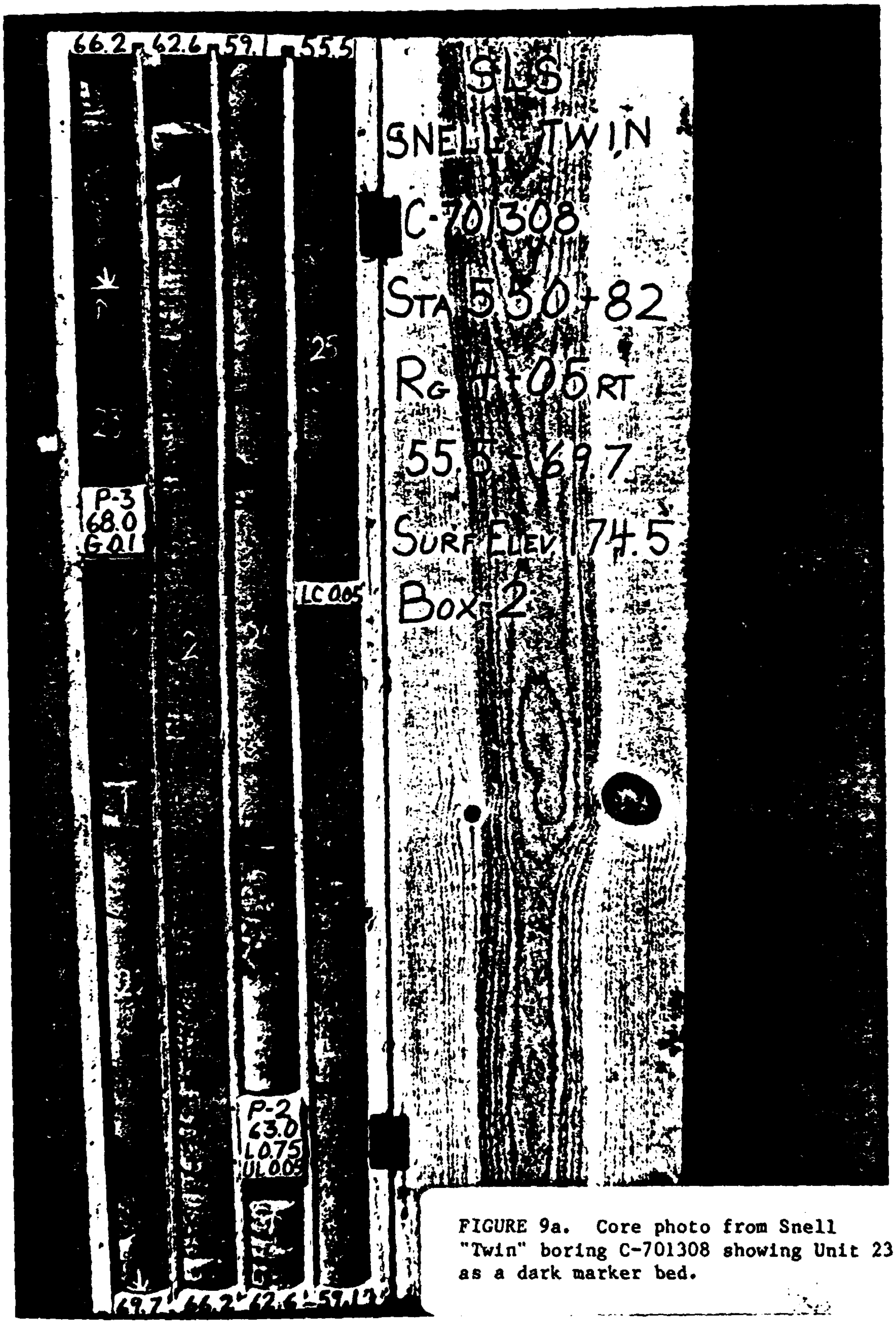


FIGURE 9a. Core photo from Snell "Twin" boring C-701308 showing Unit 23 as a dark marker bed.

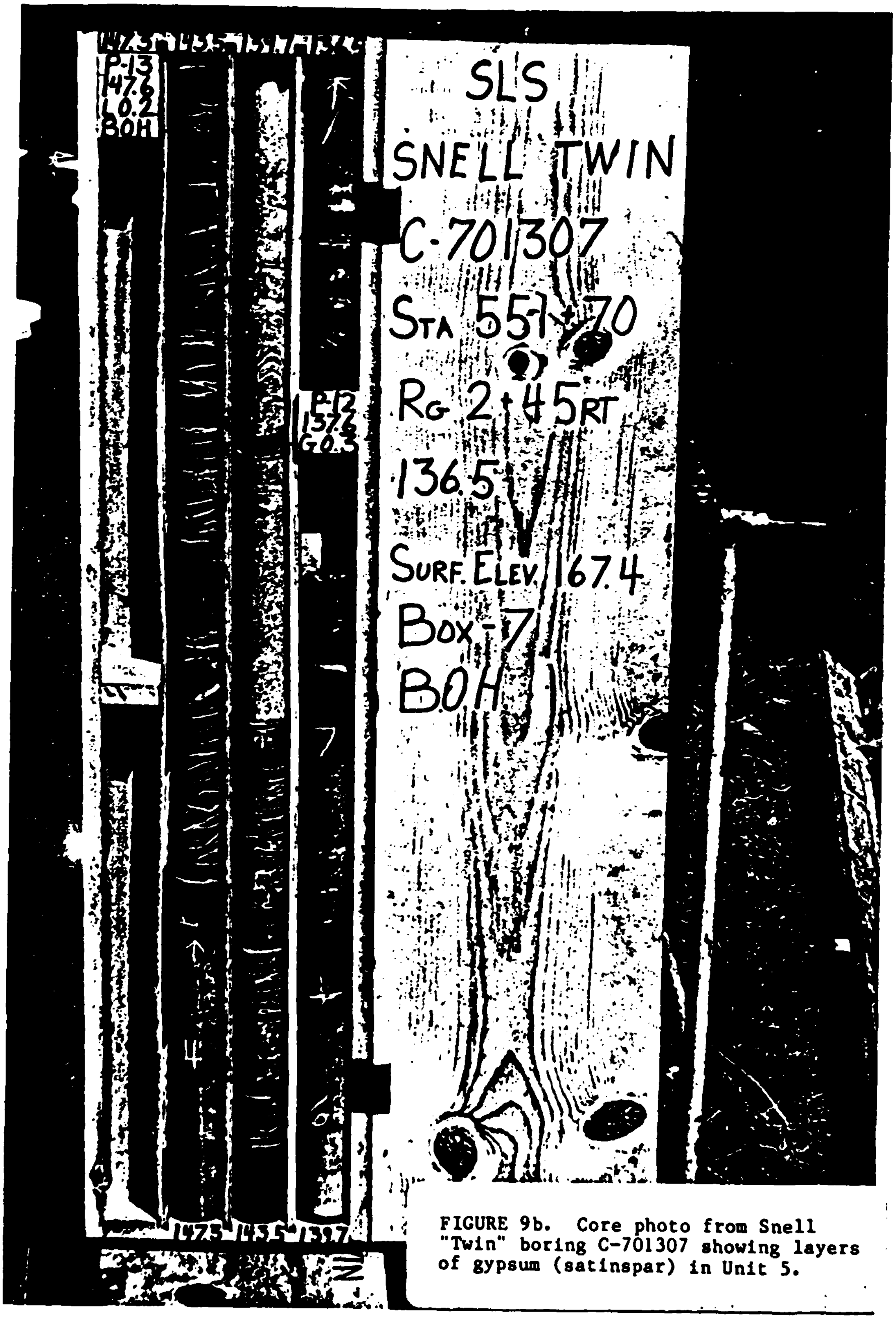
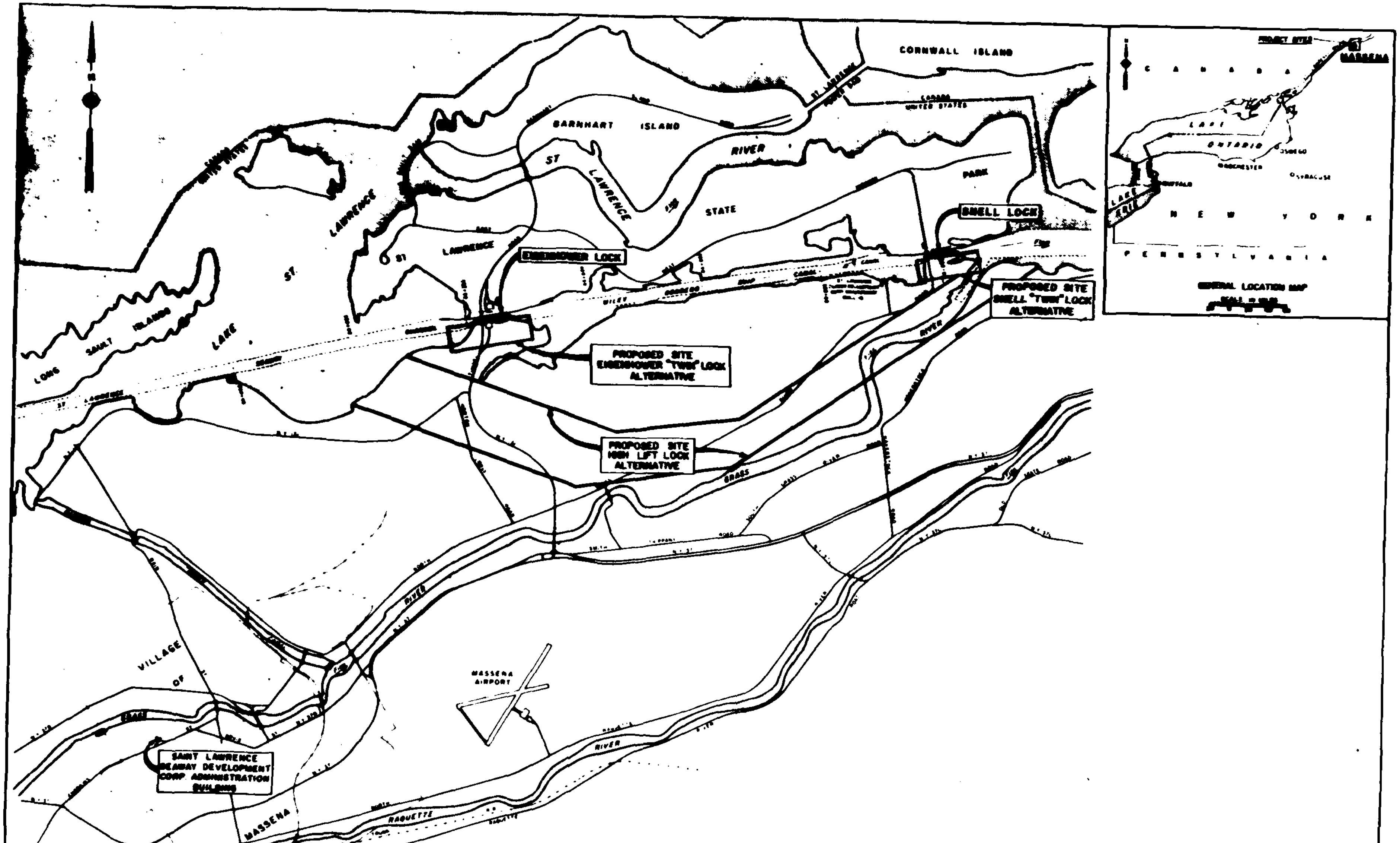


FIGURE 9b. Core photo from Snell "Twin" boring C-701307 showing layers of gypsum (satinspar) in Unit 5.



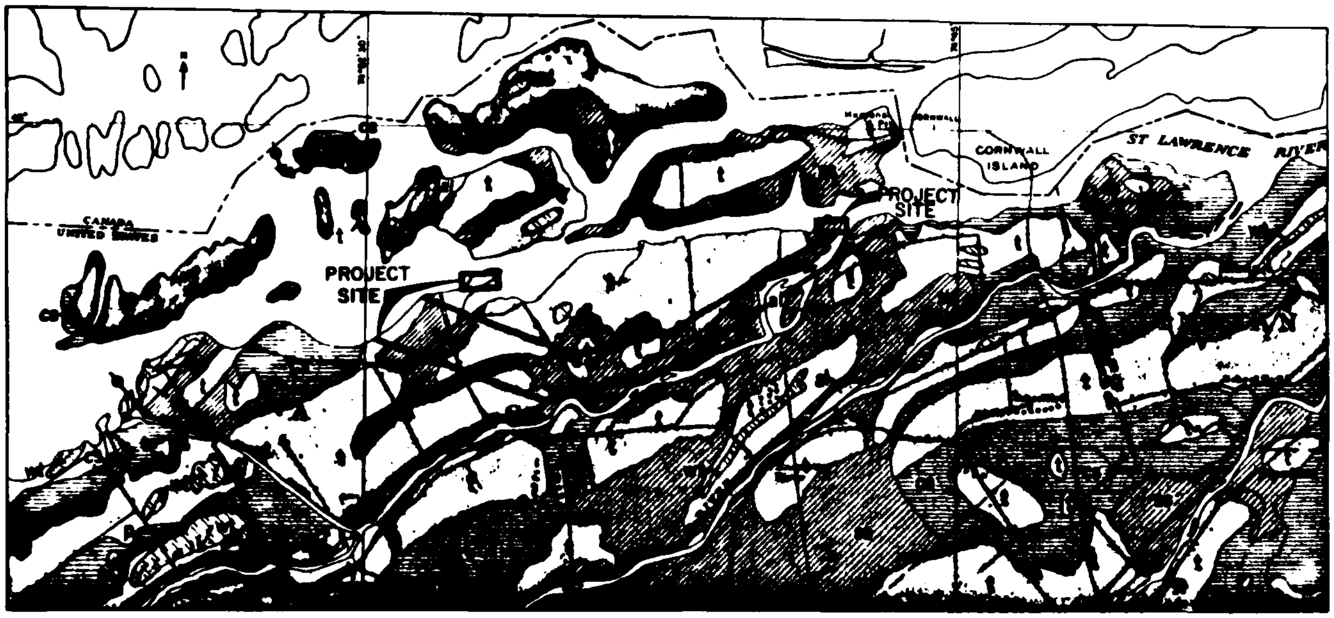
ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

VICINITY MAP
EISENHOWER & SNELL "TWIN" LOCKS
AND HIGH LIFT LOCK ALTERNATIVES

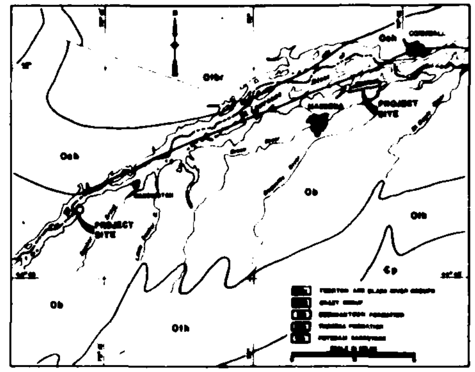
U.S. ARMY ENGINEER DISTRICT, BUFFALO
GEOTECHNICAL REPORT MARCH 1981

PLATE 1

SURFICIAL GEOLOGY - VICINITY, IROQUOIS LOCK - PT. ROCKWAY ALTERNATIVE



SURFICIAL GEOLOGY - VICINITY, SNELL "TWIN", EISENHOWER "TWIN" AND HIGH LIFT LOCK ALTERNATIVES



BEDROCK GEOLOGY OF NORTHERN NEW YORK

LEGEND

- Till (little or no morainal topography)
- wt — Winnowed till (coarse poorly rounded gravel)
- Sand, silty (widespread but not thick sheets on the lowlands deposited during the shoaling phase of lake or sea.)
- Clay, silty (deposited in lowlands by either lake or sea)
- Dune sand
- al — Alluvium
- Peat and muck
- Striae
- Till fabric
- Gravel pit
- Boulders

NOTES

1 Map of bedrock geology taken from: Fisher, Donald W., et al, eds., Geologic Map of New York, Map and Chart Series No 5, State Museum and Science Service, Geological Survey, Albany, N.Y., [illegible]

2 Surficial geology maps taken from: MacClintock, Paul, and Stewart, David P., Pleistocene Geology of the St. Lawrence Lowland, Bull. No. 394, State Museum and Science Service Albany, N.Y. 1965.

SCALE IN MILES

1/2 0 1/2 1 1½ 2

ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

REGIONAL / NEAR REGIONAL
BEDROCK AND SURFICIAL GEOLOGY

US ARMY ENGINEER DISTRICT, BUFFALO
GEOTECHNICAL REPORT MARCH 1981

PLATE 2

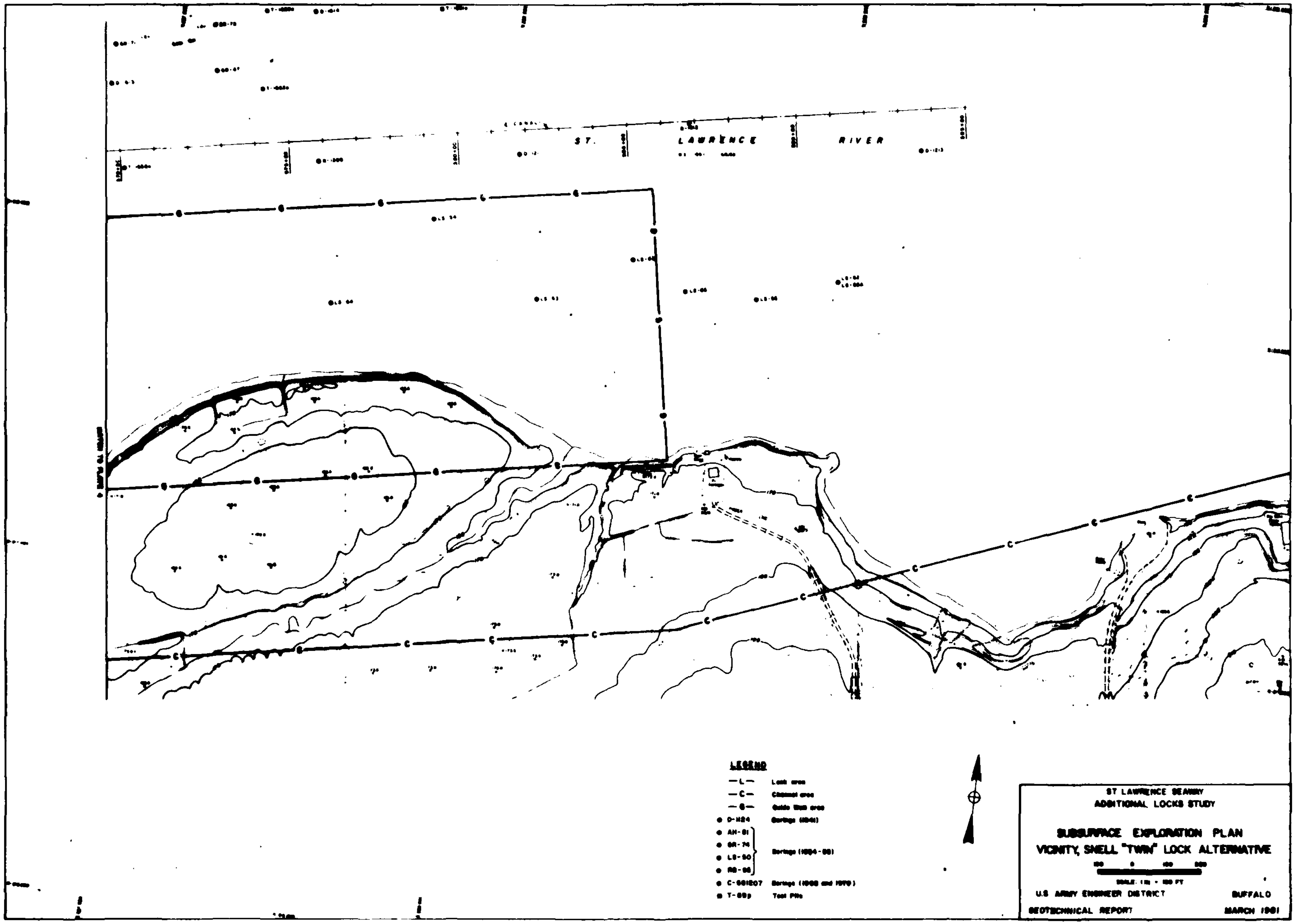
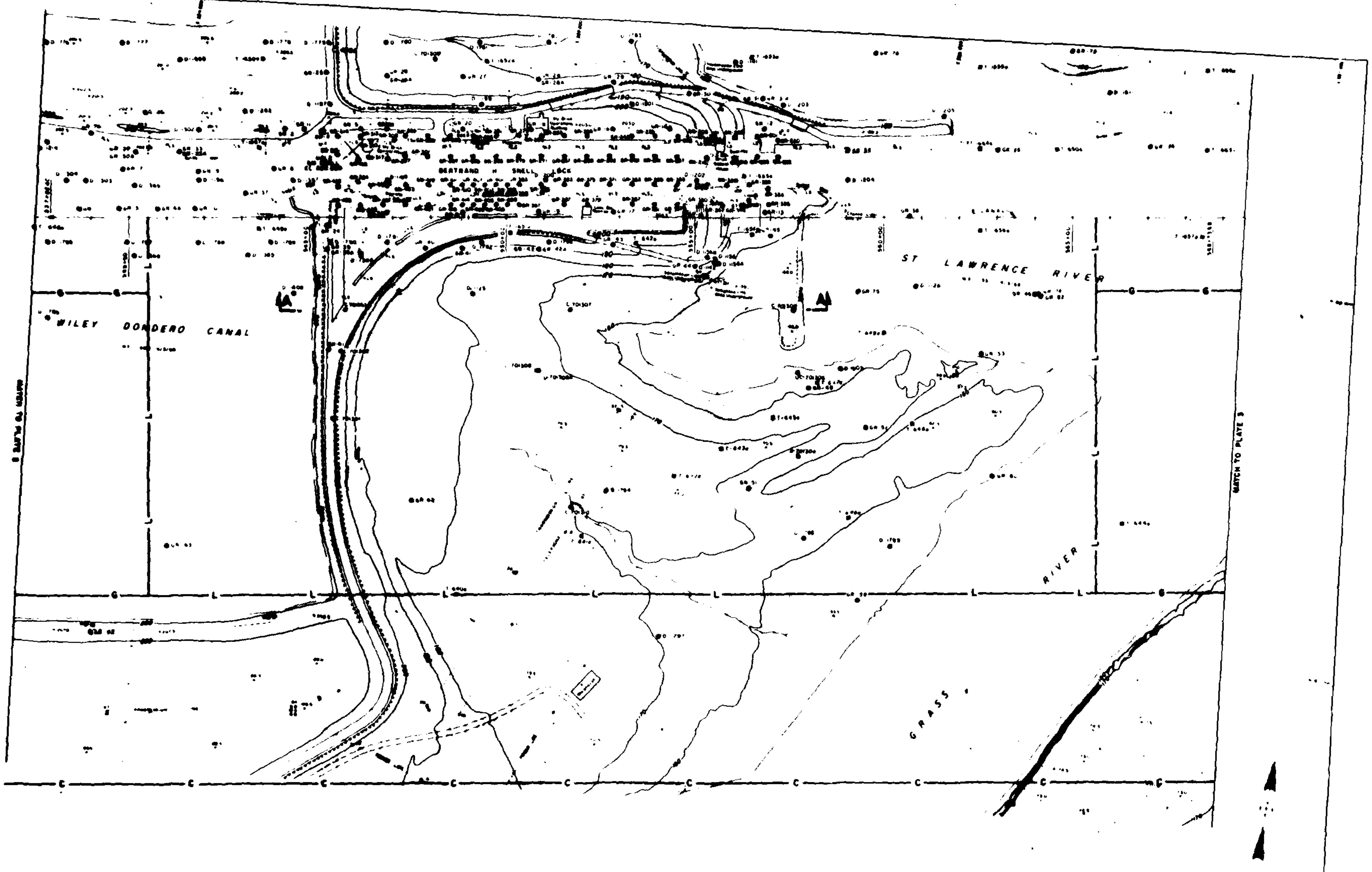

ST. LAWRENCE RIVER
MATCH TO PLATE 4
LEGEND
Lock area
Channel area
Guide Wall area
Test Pits
ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY
SUBSURFACE EXPLORATION PLAN
VICINITY, SNELL "TWIN" LOCK ALTERNATIVE
U.S. ARMY ENGINEER DISTRICT
BUFFALO
GEOTECHNICAL REPORT
MARCH 1981

PLATE 3



NOTES

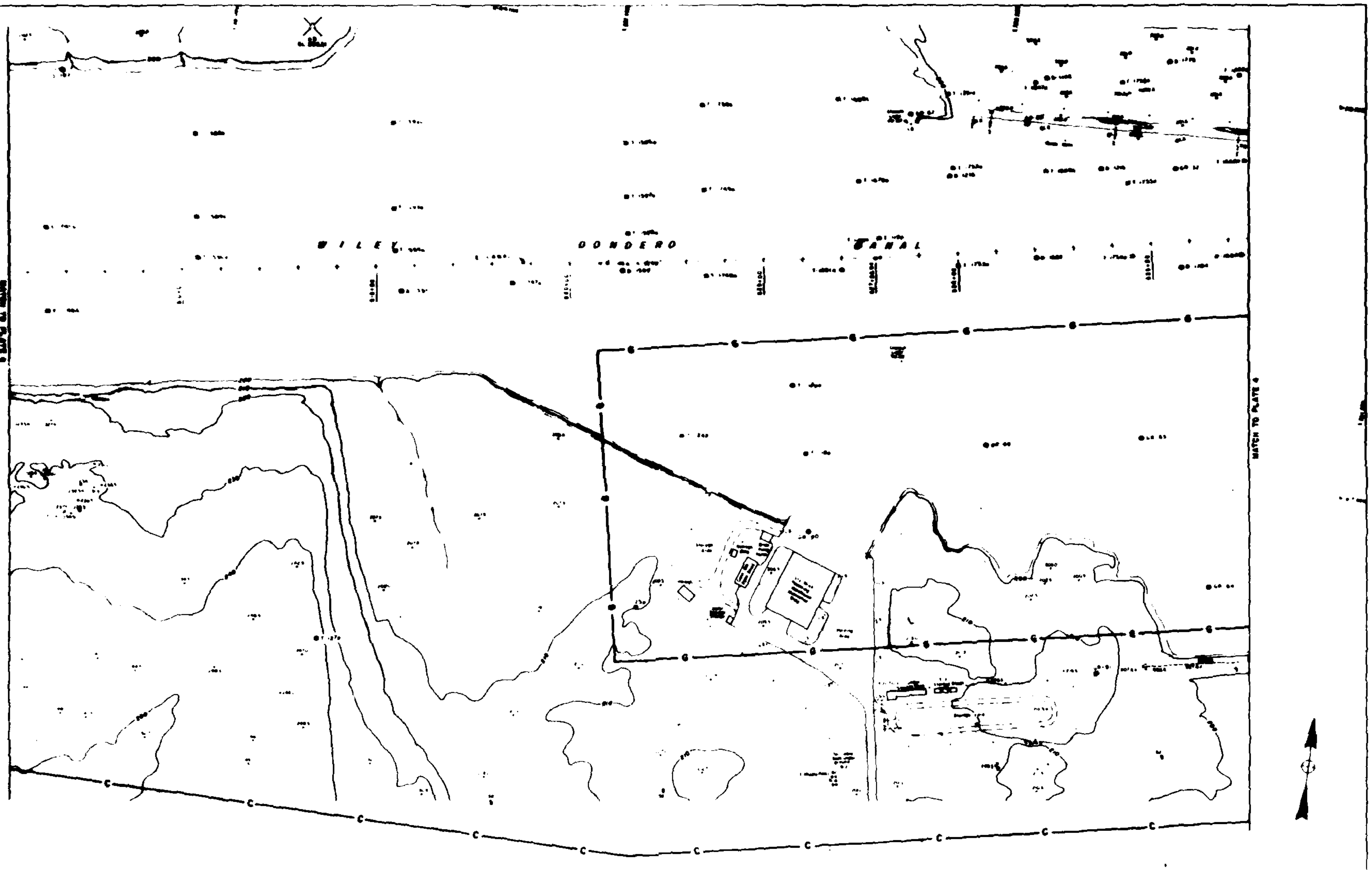
1. For legend refer to Plate 3
2. For Profile A-A, refer to Plate 6

ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

SUBSURFACE EXPLORATION PLAN
VICINITY, SNELL "TWIN" LOCK ALTERNATIVE

U.S. ARMY ENGINEER DISTRICT, BUFFALO
GEOTECHNICAL REPORT
MARCH 1981

PLATE 4



NOTE
For legend, refer to Plate 3

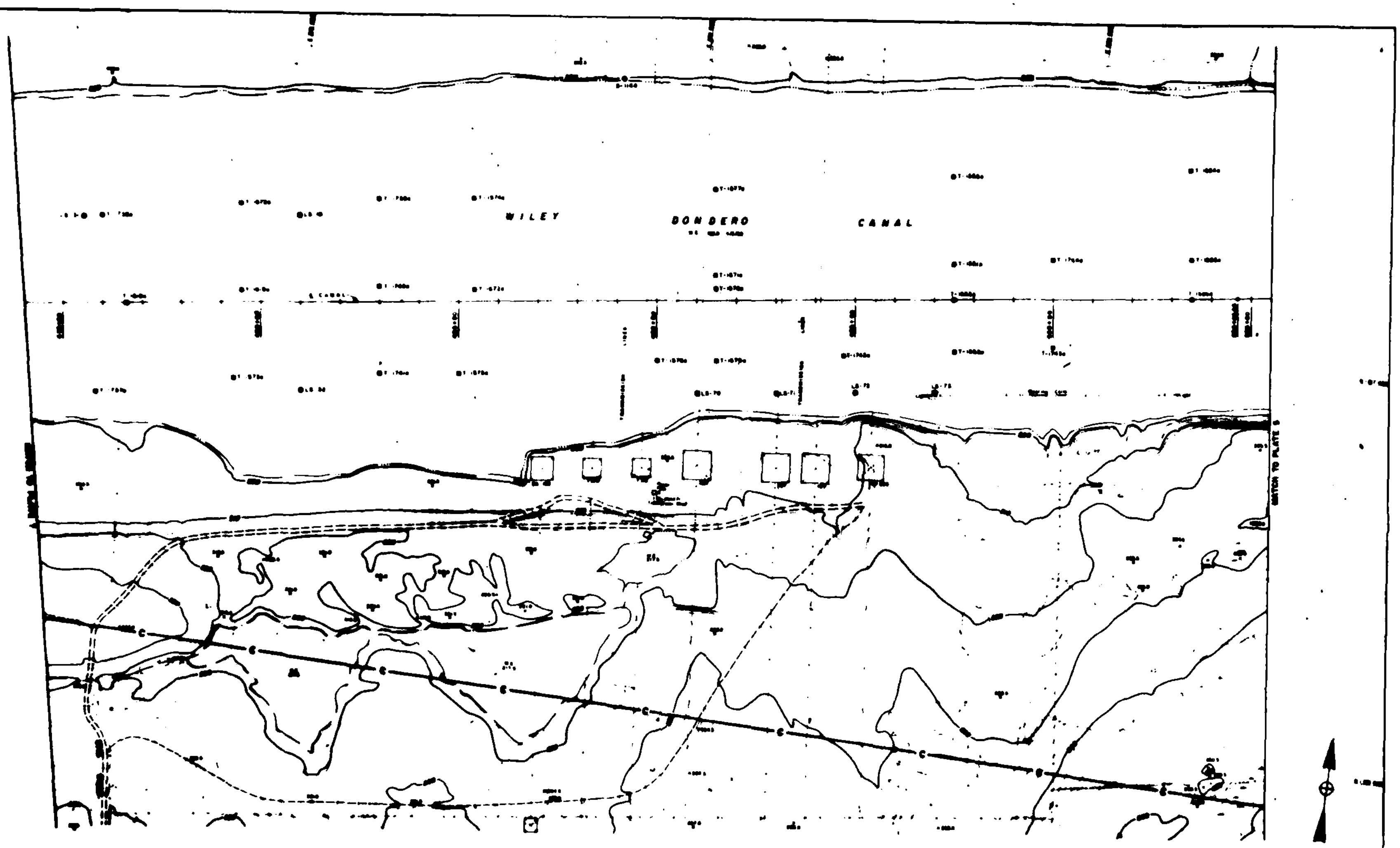
ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

SUBSURFACE EXPLORATION PLAN
VICINITY, SNELL "TWIN" LOCK ALTERNATIVE

SCALE: 1 IN = 100 FT

US ARMY ENGINEER DISTRICT, BUFFALO
GEOTECHNICAL REPORT MARCH 1981

PLATE 5



NOTE
For legend, refer to Plate 5.

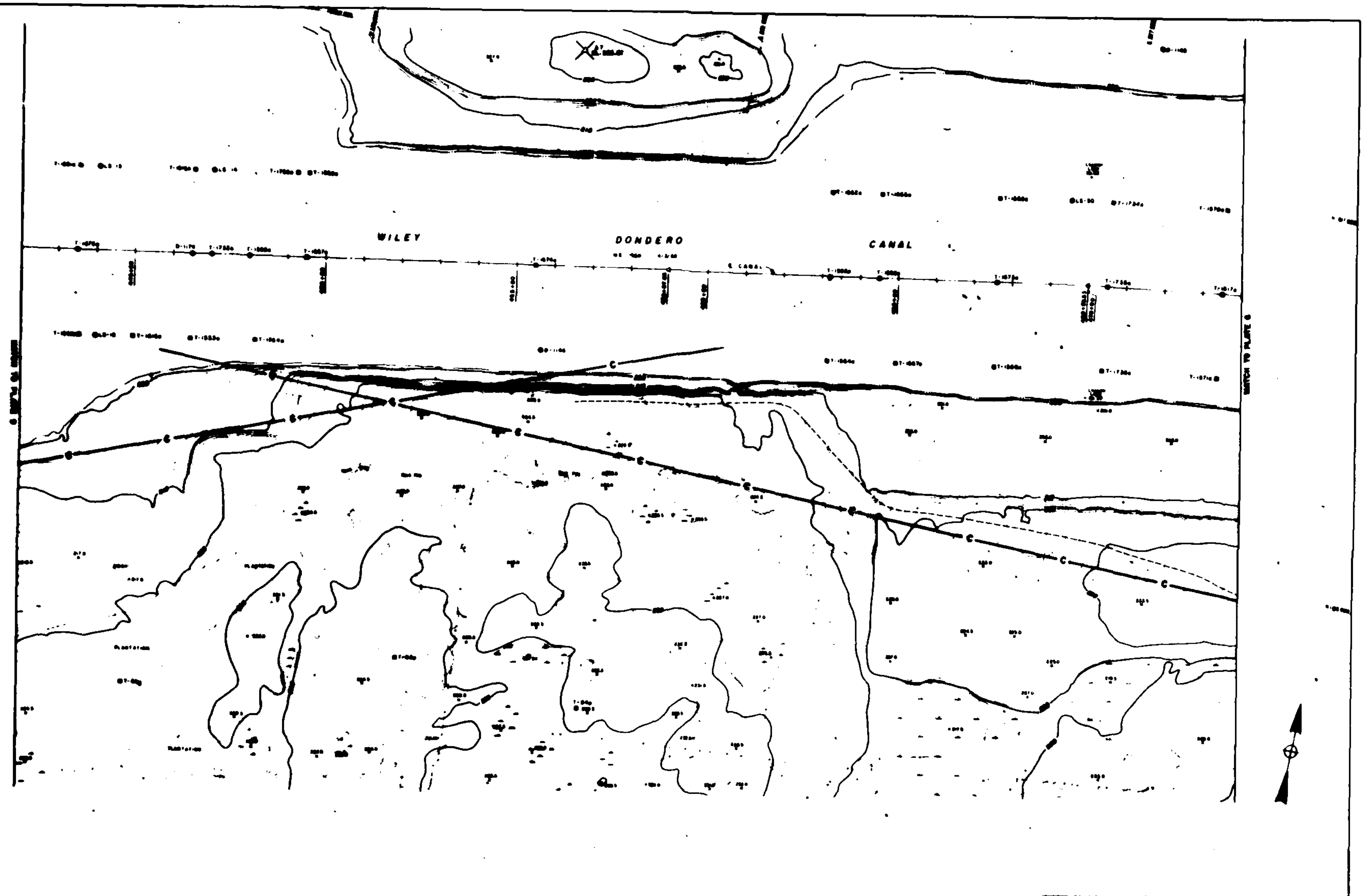
ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

SUBSURFACE EXPLORATION PLAN
VICINITY, SNELL "TWIN" LOCK ALTERNATIVE

SCALE: 1 IN. = 200 FT.

US ARMY ENGINEER DISTRICT, BUFFALO
GEOTECHNICAL REPORT MARCH 1981

PLATE 6



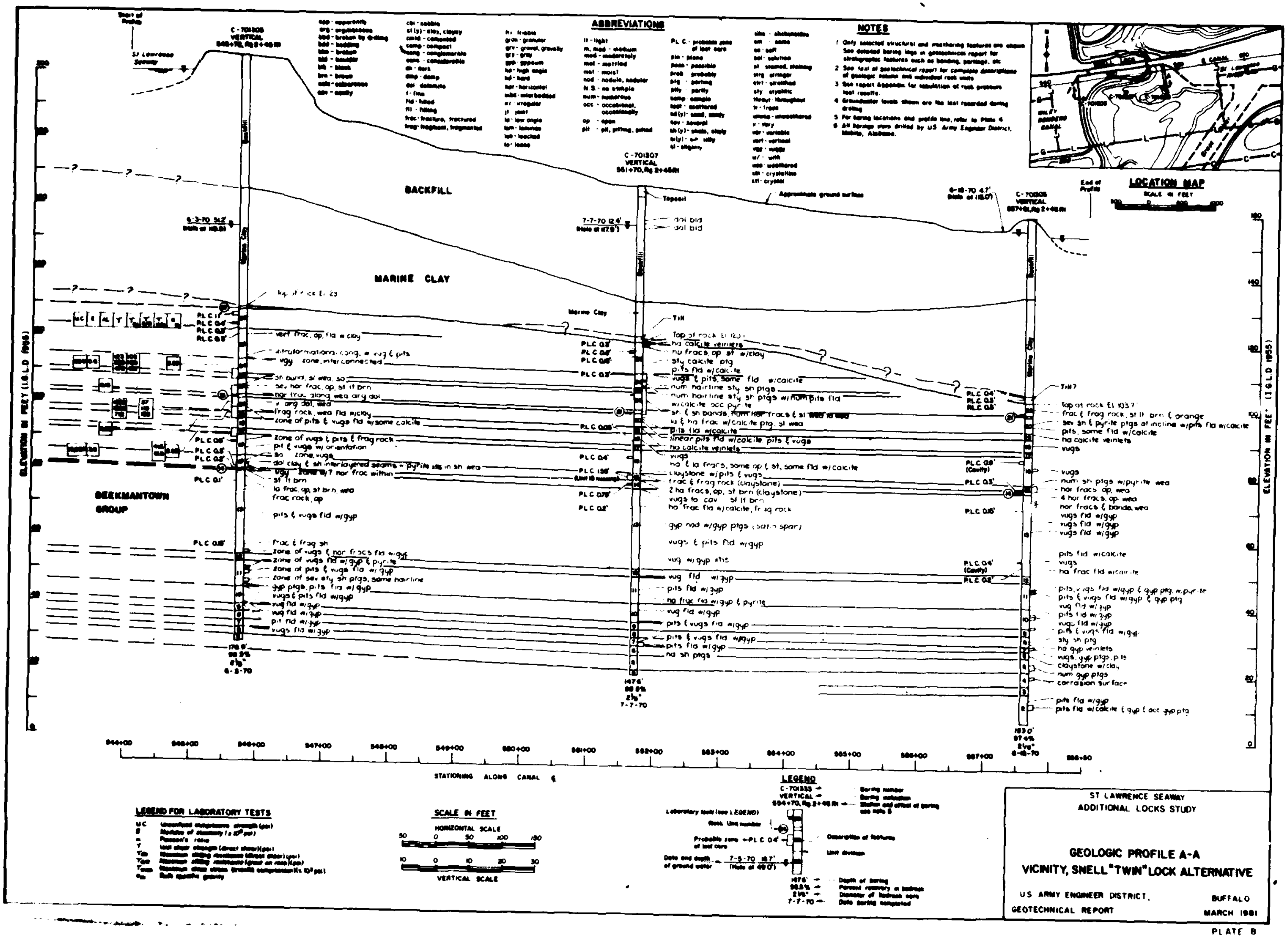
NOTE
For legend, refer to Plate 5.

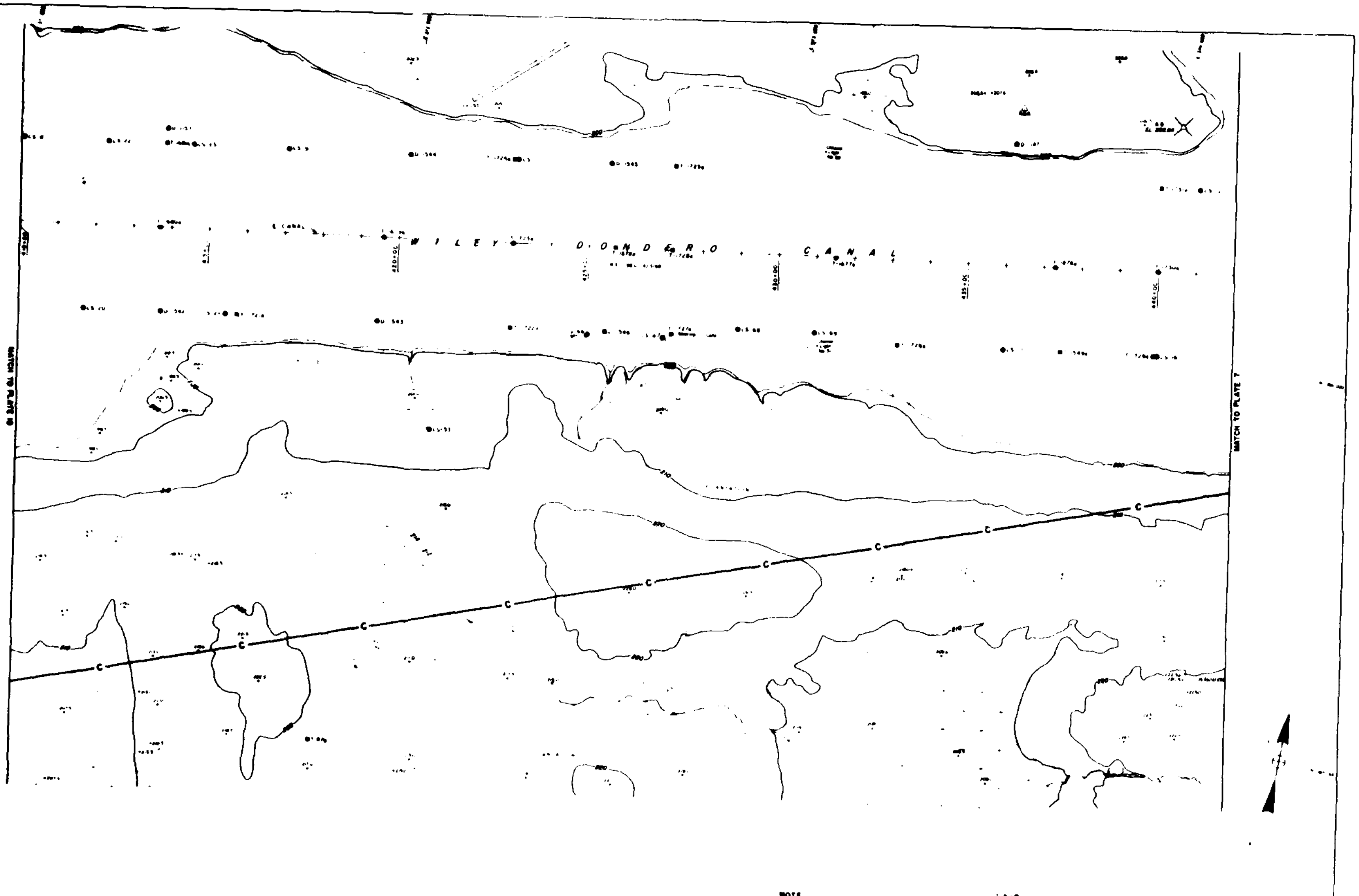
ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

SUBSURFACE EXPLORATION PLAN
VICINITY, SNELL "TWIN" LOCK ALTERNATIVE

US ARMY ENGINEER DISTRICT, BUFFALO
GEOTECHNICAL REPORT
MARCH 1981

PLATE 7


ABBREVIATIONS
NOTES
LOCATION MAP
BACKFILL
MARINE CLAY
BEEKMANTOWN GROUP
C-701306 VERTICAL
C-701307 VERTICAL 561+70, Rg 2+46 Rt
C-701308 VERTICAL
Approximate ground surface
ELEVATION IN FEET (I.G.L.D 1955)
STATIONING ALONG CANAL ℄
LEGEND FOR LABORATORY TESTS
SCALE IN FEET
HORIZONTAL SCALE
VERTICAL SCALE
LEGEND
ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY
GEOLOGIC PROFILE A-A
VICINITY, SNELL "TWIN" LOCK ALTERNATIVE
US ARMY ENGINEER DISTRICT, BUFFALO
GEOTECHNICAL REPORT
MARCH 1981
PLATE 8



NOTE:
For legend, refer to Plate 3

ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

SUBSURFACE EXPLORATION PLAN
VICINITY, EISENHOWER "TWIN" LOCK ALTERNATIVE

100 0 100 200
SCALE 1 IN = 100 FT

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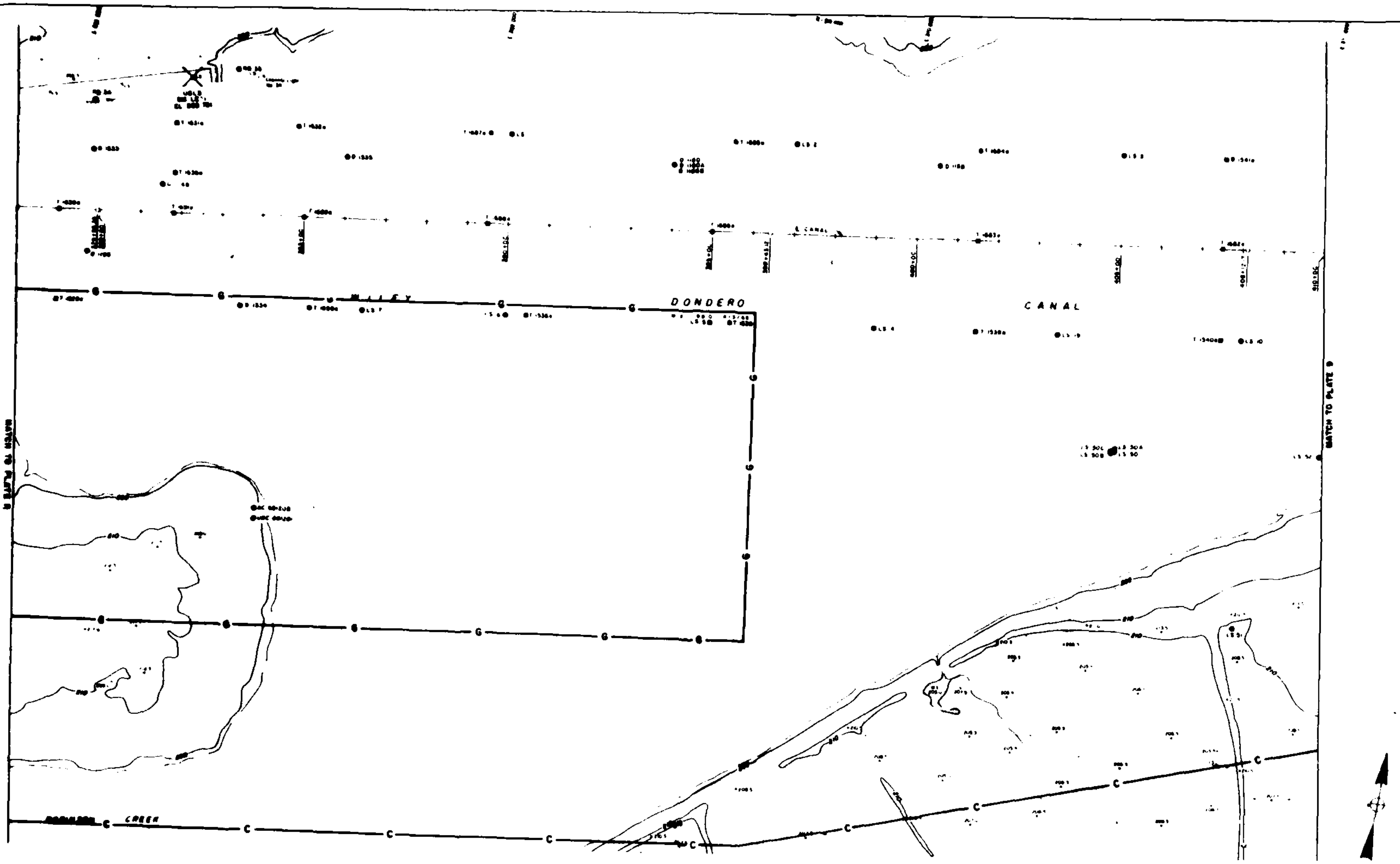
PLATE 9



NOTE
For legend, refer to Plate 5

ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

SUBSURFACE EXPLORATION PLAN
VICINITY, EISENHOWER "TWIN" LOCK ALTERNATIVE

100 0 100 200
SCALE 1 IN = 100 FT

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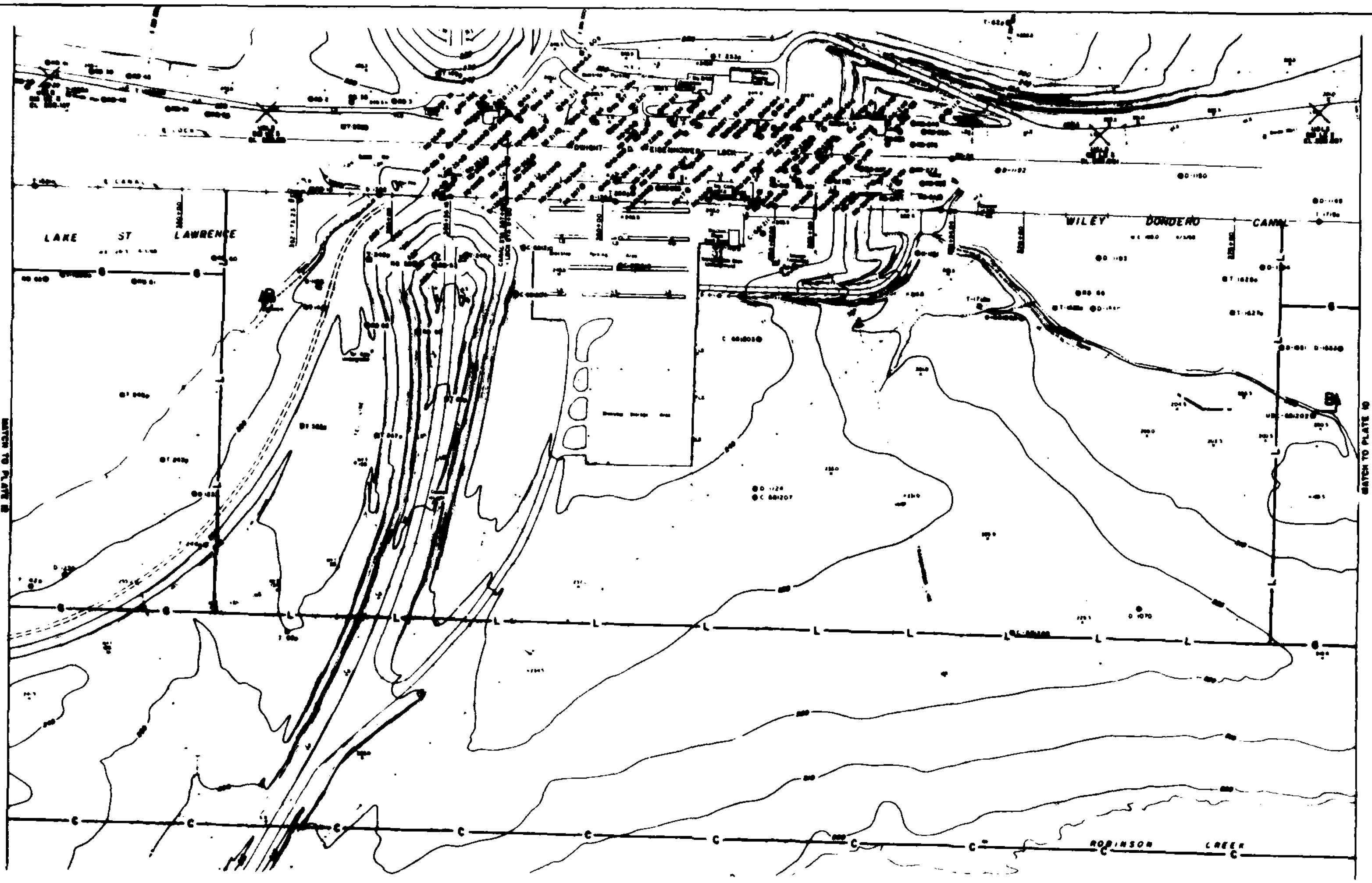
PLATE 10



NOTES:
1 For legend, refer to Plate 5
2 For Profile B-B, refer to Plate 16.

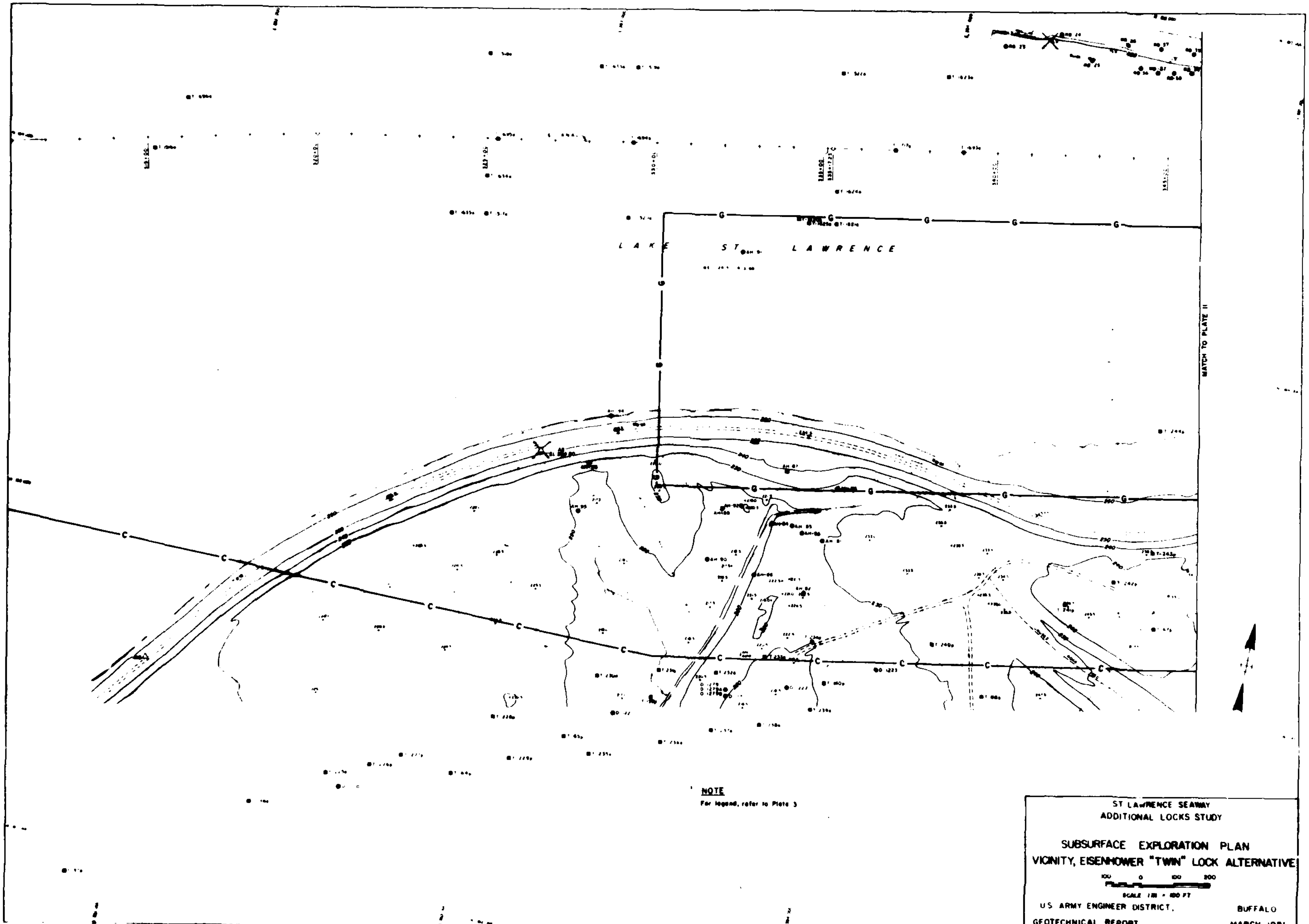
ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

SUBSURFACE EXPLORATION PLAN
VICINITY, EISENHOWER "TWIN" LOCK ALTERNATIVE

SCALE 1 IN = 100 FT

U S ARMY ENGINEER DISTRICT, BUFFALO
GEOTECHNICAL REPORT MARCH 1981

PLATE 11



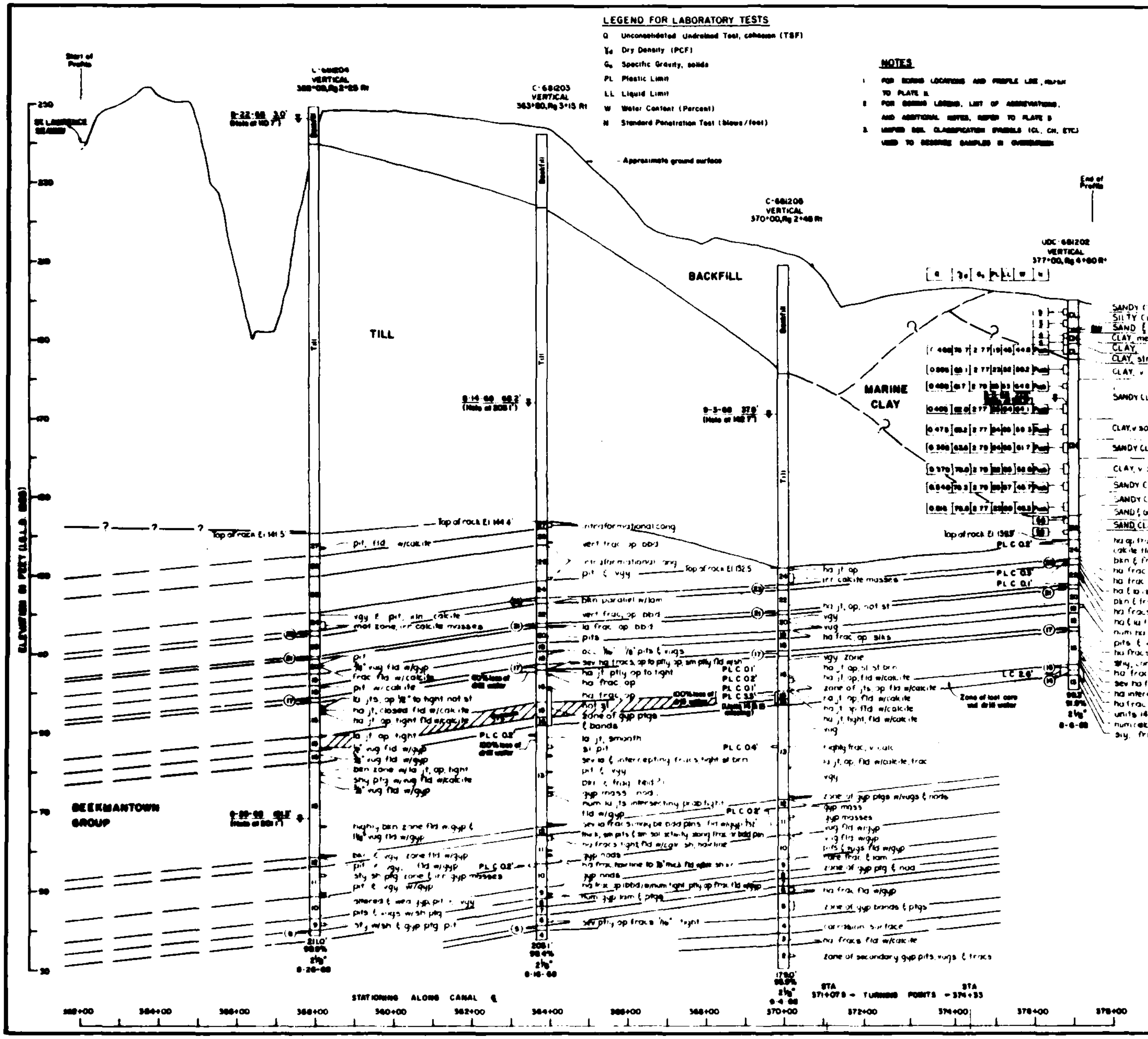
ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

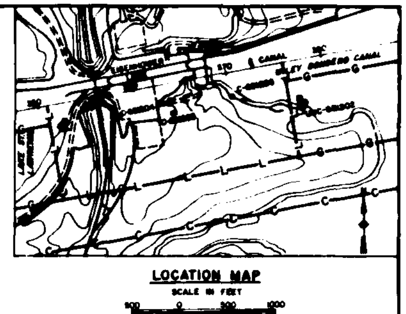
SUBSURFACE EXPLORATION PLAN
VICINITY, EISENHOWER "TWIN" LOCK ALTERNATIVE

SCALE 1 IN = 100 FT

US ARMY ENGINEER DISTRICT, BUFFALO
GEOTECHNICAL REPORT MARCH 1981

PLATE 12





SCALE IN FEET

HORIZONTAL SCALE

VERTICAL SCALE

ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

GEOLOGIC PROFILE B-B

VICINITY, EISENHOWER "TWIN" LOCK ALTERNATIVE

US ARMY ENGINEER DISTRICT BUFFALO

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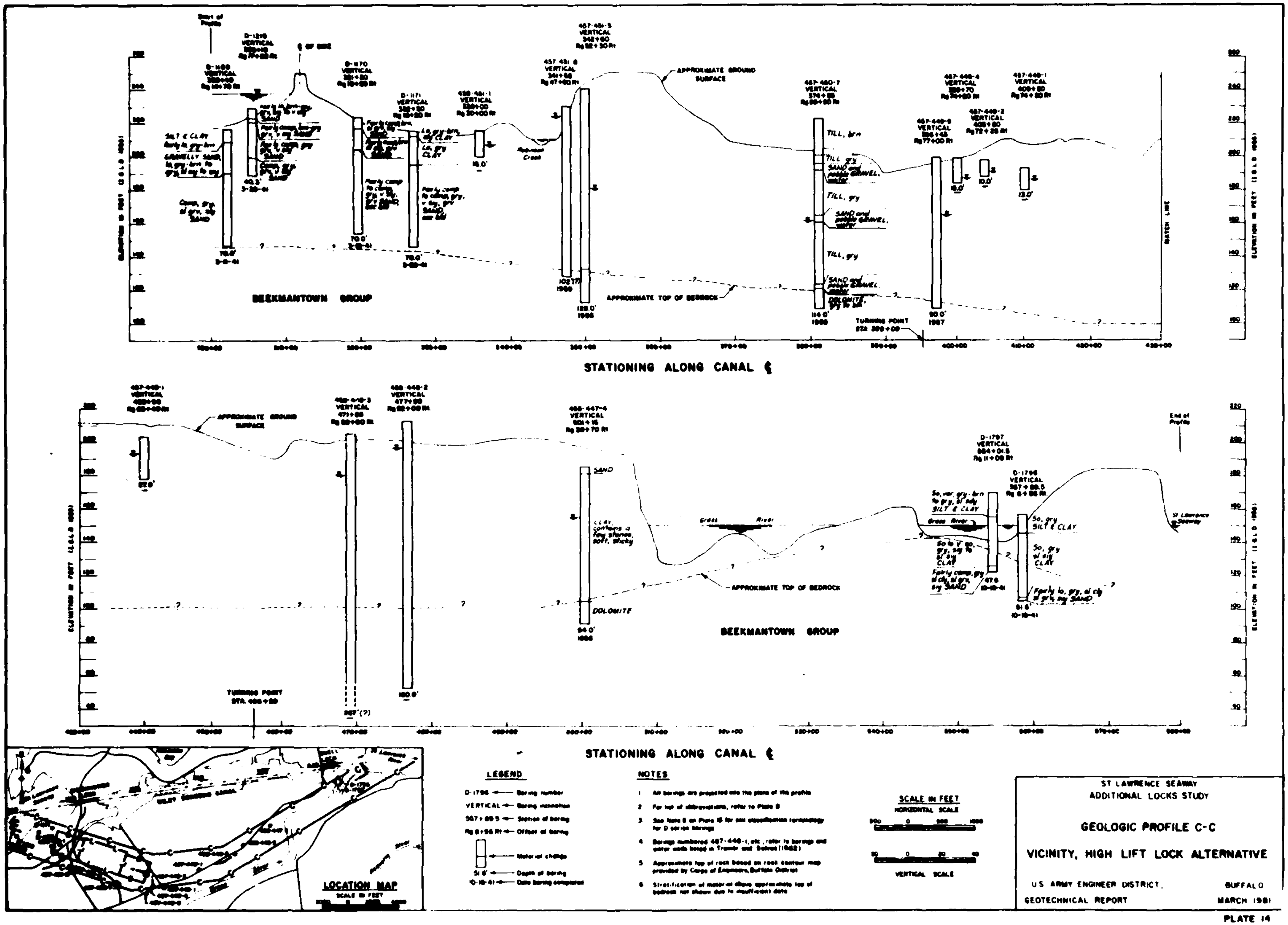
PLATE 13



STATIONING ALONG CANAL ℄
APPROXIMATE GROUND SURFACE
APPROXIMATE TOP OF BEDROCK
BEEKMANTOWN GROUP
TURNING POINT STA 399+00
TURNING POINT STA 466+30
MATCH LINE
STATIONING ALONG CANAL ℄
BEEKMANTOWN GROUP
APPROXIMATE GROUND SURFACE
APPROXIMATE TOP OF BEDROCK
Grass River
St Lawrence Seaway
End of Profile
LOCATION MAP
LEGEND
NOTES
SCALE IN FEET
HORIZONTAL SCALE
VERTICAL SCALE
ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY
GEOLOGIC PROFILE C-C
VICINITY, HIGH LIFT LOCK ALTERNATIVE
U.S. ARMY ENGINEER DISTRICT, BUFFALO
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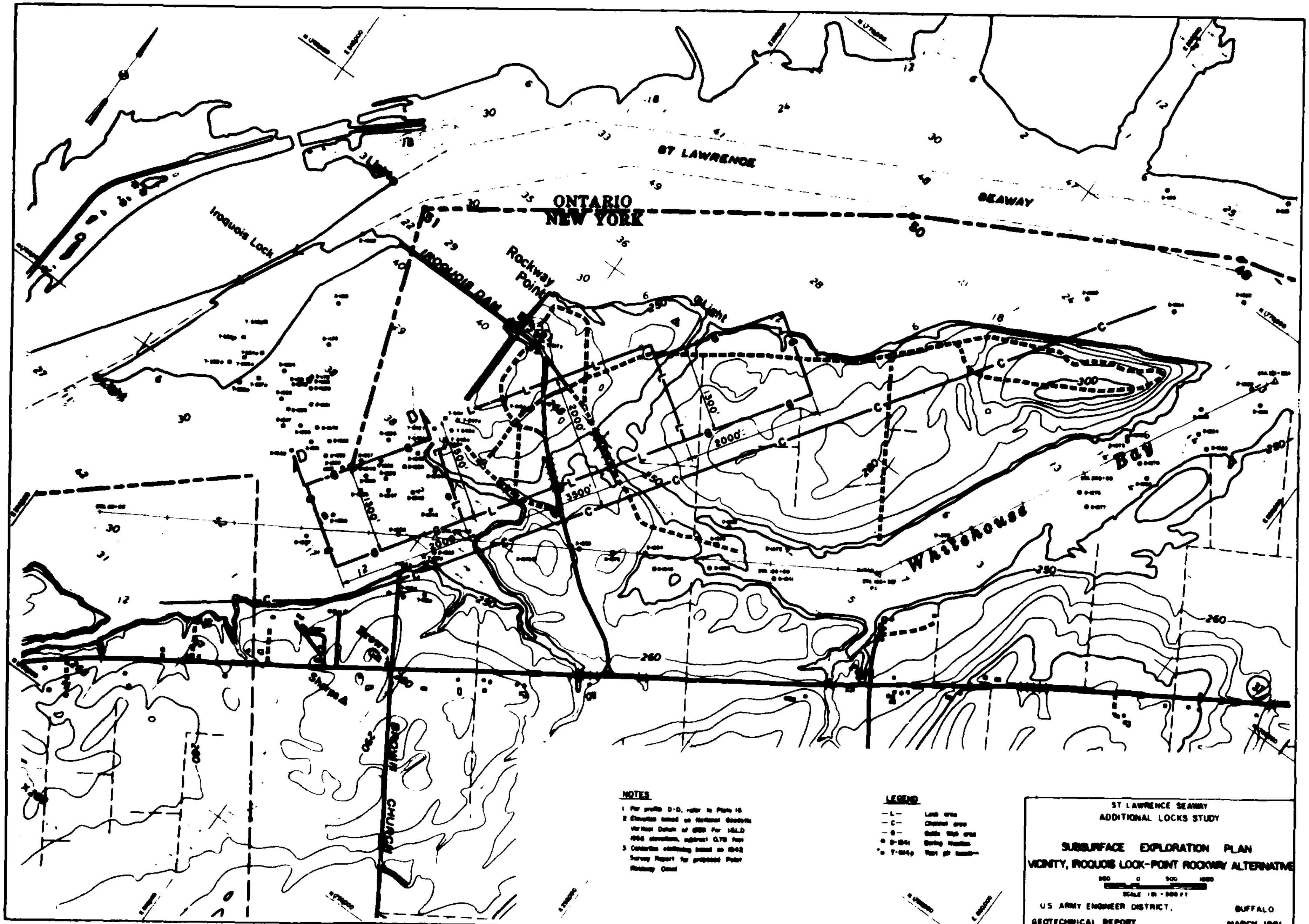
PLATE 14


ONTARIO
NEW YORK
ST LAWRENCE
SEAWAY
Iroquois Lock
IROQUOIS DAM
Rockway Point
Whitehouse Bay
BROWN CHURCH
NOTES
LEGEND
ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY
SUBSURFACE EXPLORATION PLAN
VICINITY, IROQUOIS LOCK-POINT ROCKWAY ALTERNATIVE
U S ARMY ENGINEER DISTRICT, BUFFALO
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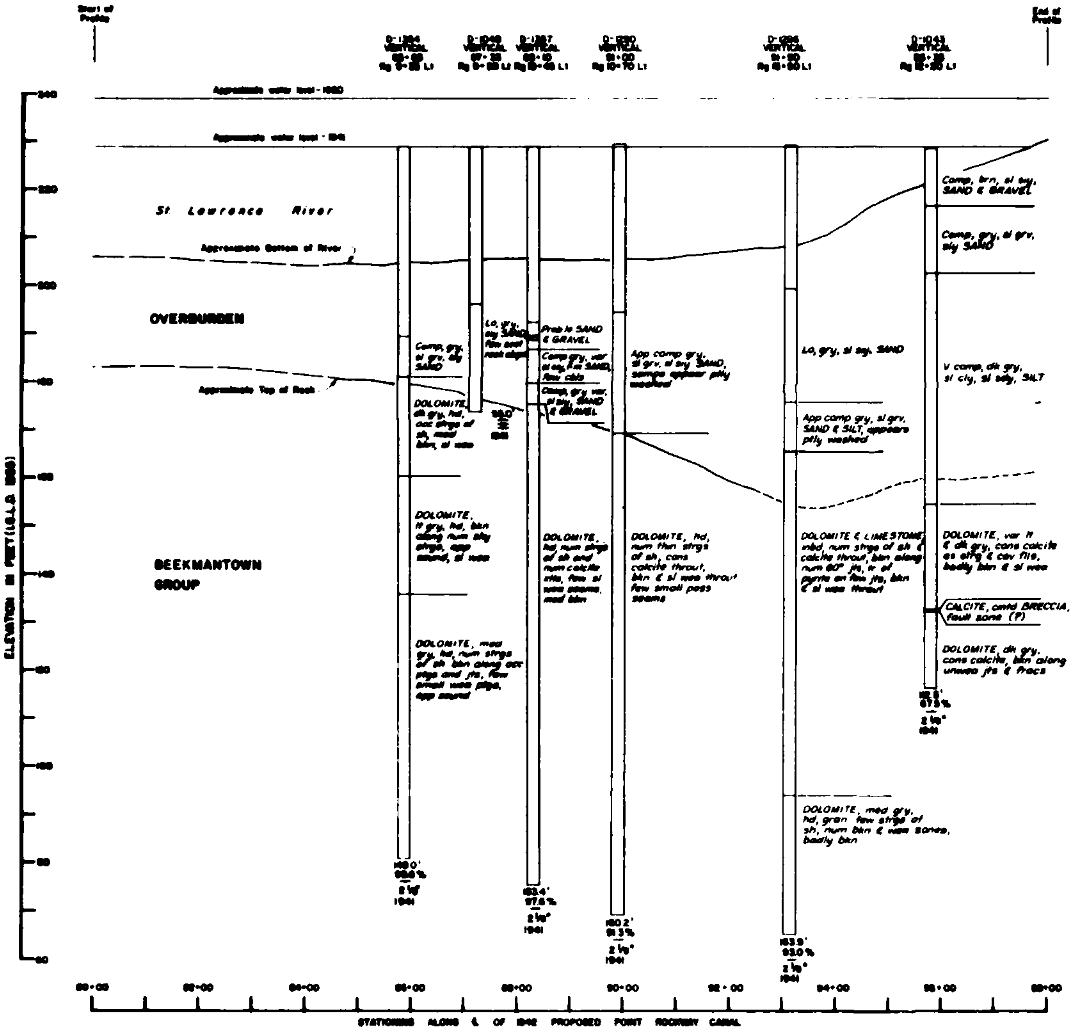
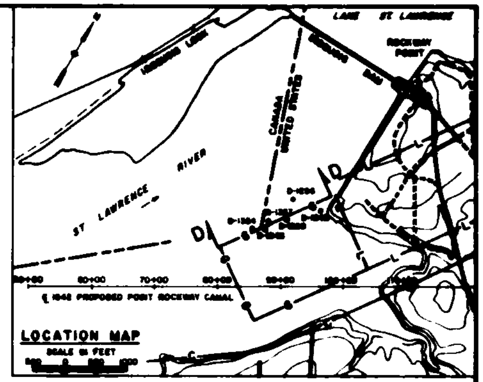
MARCH 1981

PLATE 15

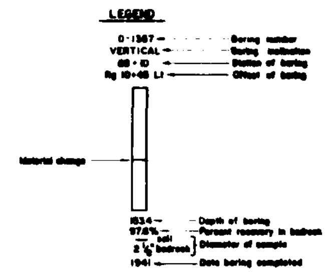




LOCATION MAP

SCALE IN FEET

LEGEND



NOTES

1. The original elevations were based on Mean Sea Level Datum (1912 Adj) and have been converted to International Great Lakes Datum (1955)
2. All borings are projected into the plane of the profile
3. Analyses of overburden material are based on drive sampling. Analyses of rock are based on cores obtained from drilling
4. For boring locations and profile line, refer to Plate 15.
5. The soil classification shown uses the following terminology to denote the percentage by dry weight of each component:

Term	Proportion
"slightly"	1 - 20%
"adjective"	20 - 40%
"and"	40 - 50%

6. During 1941 boring program, river level was at approximately El 228.8 feet (I.G.L.D 1955). After construction of Iroquois Dam, river level rose to El 239.1 feet (I.G.L.D 1955) - present low water datum above Iroquois Dam.
7. Approximate top of rock taken from: Folio of Subsurface Exploration, Final Report 1942, Appendix D-1, St Lawrence River Project, U S Engineer Office, Massena, N Y, Plate 18.

ST LAWRENCE SEAWAY
ADDITIONAL LOCKS STUDY

GEOLOGIC PROFILE D-D
VICINITY, IROQUOIS LOCK -
POINT ROCKWAY ALTERNATIVE

U S ARMY ENGINEER DISTRICT, BUFFALO
GEOTECHNICAL REPORT MARCH 1981

PLATE 16

END

DATE FILMED

4-82

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